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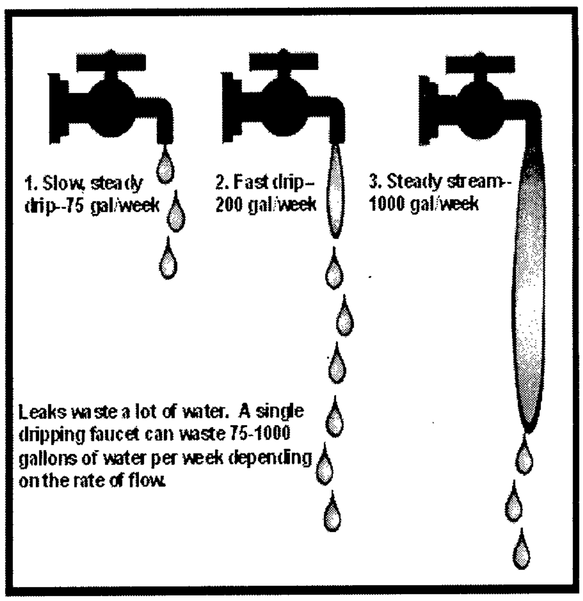
Water Efficient Installations

Techniques and Technology

by
Richard J. Scholze, Robert J. Nemeth, and Richard L. Gebhart



Water conservation is not only good practice, but has become a political necessity and a mandate. Military installations are required to take steps to identify and implement appropriate technology/techniques to effect water conservation. The dynamics of water use on military installations are different than in civilian communities. Studies of the effectiveness of conservation measures in civilian communities may not directly apply to the military. Assessment of the actual impact of conservation measures on military installations is necessary to provide data for use in estimating payback periods for compliance with Executive Order 12902 and the Energy Policy Act, and to establish an effective water conservation program.

Use of water saving fixtures, alternative landscaping scenarios, leak detection, and demand side management, the reuse of water, and other methodologies provide opportunities for finding additional water supplies from within existing resources. These practices and technologies are associated with reduction in energy consumption and can also provide additional resource savings. This report provides a menu of alternatives for installations to choose from to respond to water conservation mandates.

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Foreword

This study was conducted for U.S. Army Center for Public Works (USACPW) through funding supplied by the Utilities Division of ACSIM (Assistant Chief of Staff for Installation Management). Funding for publication was supplied by Headquarters, U.S. Marine Corps. The technical monitor was Jane Anderson, CECPW-ES.

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Background

Federal facilities are required by Executive Order 12902 (8 March 1994) Energy Efficiency and Water Conservation at Federal Facilities, and the Energy Policy Act of 1992 (EPAct) (26 October 1992) to implement all water conservation measures that pay back in 10 years or less by 2005. The dynamics of water use on military installations are different than in civilian communities, e.g., on military installations, residents have no financial incentive to conserve water, commanders can require implementation of conservation, etc. Therefore, studies of the effectiveness of conservation measures in civilian communities may not directly apply to the military. Assessment of the actual impact of conservation measures on military installations is necessary to provide data for use in estimating payback periods for compliance with the Executive Order and the Energy Policy Act, and to establish an effective water conservation program.

Water conservation, which is simply the wise use of an important resource, is not only good practice, but has become a political necessity and a mandate. Military installations are required to take a number of steps to identify and implement appropriate technology/techniques to effect water conservation. In some areas of the country, not just the arid West but also in the East, available water resources are overburdened, and development of additional resources has become a political liability or an extremely costly venture. Use of water saving fixtures, alternative landscaping scenarios, reuse of water, leak detection, demand side management, and other methodologies are opportunities for finding additional water supplies from within existing resources. These practices and technologies are also associated with reductions in energy consumption, and can provide additional resource savings.

Objective

The objective of this study was to provide a menu of options for installations to choose from to respond to the water conservation mandates of the Energy Policy Act and Executive Order 12902.

Approach

The objective was met by identifying implementable techniques/technologies for Army installations. Extensive review of the literature, both primary and secondary, and examination of manufacturers' literature contributed to this report.

Metric Conversion Factors

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

1 in.	=	25.4 cm
1 ft	=	0.305 m
1 yd	=	0.9144 m
1 sq in.	=	6.452 cm^2
1 sq ft	=	0.093 m^2
1 sq yd	=	0.836 m^2
1 cu in.	=	16.39 cm^3
1 cu ft	=	0.028 m^3
1 cu yd	=	0.764 m^3
1 acre	=	0.407 ha
1 gal	=	3.78 L
1 lb	=	0.453 kg
1 kip	=	453 kg
1 psi	=	6.89 kPa
1 hp	=	746 W
°F	=	(°C x 1.8) + 32

2 Why Water Conservation?

Legislation, Executive Orders

A major conservation milestone was achieved in 1992 with the establishment of national water efficiency requirements for plumbing products through the Federal Energy Policy Act of 1992. Once fully implemented, and when the current stock of high-volume plumbing fixtures is fully replaced (around the year 2025), the new efficiency standards will result in water savings of thousands of gallons of water per year per household from current demand. Nationally, the total U.S. demand is predicted to decrease by about 6 to 9 billion gal/day. There are three basic components to the water efficiency requirements of the Energy Policy Act: (1) maximum water use standards for plumbing fixtures, (2) product marking and labeling requirements, and (3) recommendations for State and local incentive programs to accelerate fixture replacement.

Since January 1994, the Federal government requires that there be uniform maximum water use standards for almost every toilet (1.6 gal per flush [gpf]), urinal (1.0 gpf), showerhead (2.5 gallons per minute [gpm]) and faucet (2.5 gpm) manufactured and installed in the United States. Exemptions to the standards are allowed for products such as safety showers and toilets and urinals used in prisons, which require special designs and higher flow rates. "Blowout" flushometer commercial toilets are allowed a higher water use rate (3.5 gpf) until they can be reliably designed to operate at a lower volume.

The legislation requires manufacturers of toilets, urinals, showerheads, and faucet products to mark and label their products with information on water use. Toilets and urinals shall bear permanent legible markings indicating water use expressed in gpf. Showerheads and faucets will have permanent legible markings identifying the flow rate, expressed in gpm or gallons per cycle (gpc).

Vickers (1993) presented water conservation policies and several initiatives to promote water conservation and integrated resource planning.

Water Integrated Resource Planning (IRP) is a planning and regulatory framework relatively new to the water industry. (For more detail, see Appendix A to this

report.) IRP is promoted by the American Water Works Association and by several States. A document was funded by the U.S. Environmental Protection Agency (USEPA) and produced by the AWWA that goes into substantial detail on the subject (AWWA 1993). Integrated Resource Planning is a nontraditional response to long-term water resource issues. IRP represents a departure from the "business as usual" approach. It is a logical way to tackle the wide range of interconnected issues that affect, and are affected by, water resource planning.

IRP is an inclusive variety of techniques to help planners determine the appropriate mix of resources for meeting consumer needs. It begins with the premise that a wide range of traditional and innovative supply- and demand-side (conservation) resources must be considered. It provides information on potential consequences and helps judge the value of tradeoffs among resource strategies. When properly applied, however, the process leads to better long-term decisions.

Vickers (1993) also reviewed *Residential Graywater Systems: California Plumbing Code Standards*. In July 1992, California passed requirements for adoption of standards for installation of graywater systems in residential buildings. Water delivery systems constructed on private property must have separate pipelines for delivery of potable and nonpotable water. The law authorizes installation of graywater systems in dwellings where the city or county with jurisdiction over it determines that the systems comply with the department's standards. Furthermore, the city or county is authorized to adopt more stringent standards or to prohibit graywater systems. Further information on use of graywater is presented in chapter 14 and Appendix B to this report. Vickers (1993) also indicated that the International Association of Plumbing and Mechanical Officials has amended the Uniform Plumbing Code to include a Graywater Appendix that provides guidance and safety information to jurisdictions considering the use of graywater systems and requirements.

A number of ordinances and model landscape codes have been developed across the country to promote more efficient irrigation for turf and landscapes. California and Florida were pioneering States in passing laws requiring local governments to consider implementing ordinances to promote landscape water efficiency. The Colorado Water Utility Council has developed a package of several water efficiency model ordinances, and several cities and counties passed efficient landscape requirements and related water waste prohibitions (Vickers 1993).

For example, in 1993, a California law established a Model Ordinance for landscape water efficiency throughout the State. Unless communities created their own local ordinance before 1993, the State rules took effect automatically. Provisions of the

law include requirements for landscape and irrigation efficiency plans for new public or developer-installed landscapes that are over 2,500 sq ft as well as a requirement that recycled water be used for landscape irrigation unless an exemption is made. Runoff is prohibited, and irrigation audits for landscaped areas over 1 acre are required every 5 years.

The Florida landscape law also established a model landscape ordinance that local governments must adopt or modify. The ordinance makes fewer requirements than the California ordinance, and only requires local governments to promote xeriscape landscaping and principles through education and public projects.

A number of cities prohibit wasteful use of water for landscaping and other outdoor activities. This also includes limits on turf or for large water features. Separate meters may also be required.

Water uses other than those for residential and landscape demands have not received as much policy and regulatory review by water conservation specialists, but there have been a few initiatives (Vickers 1993). Phoenix, Denver, and New York City all prohibit once-through cooling for large cooling systems, and the city of Fresno, CA, requires that evaporative cooling systems be equipped with efficiency devices.

Elements of water conservation are present at many levels. Duquette (1993) presents a short check list for homeowners that is of general use (reproduced in Appendix C). Behavioral strategies are additional practices that may be found useful to varying degrees (Shapiro 1993). These are also included in Appendix C. Another example of water conservation management through various stages is presented by Anderson-Rodriguez and Adams (1993) for Santa Barbara County. This is also presented in Appendix C.

Governments can also regulate use. For example, regulations requiring more efficient toilets and faucet aerators have been passed. Ordinances to prohibit washing hard surfaces or watering lawns in the middle of a windy day are another option. It is difficult to change and modify behavior. Educational programs can assist in explaining to consumers the value of using less water. Especially effective is teaching children at an early age some of the benefits and procedures of water conservation.

Prompt detection and repair of leaks is always near the top of any list. Water flow devices for toilets and showerheads can use 50 to 75 percent less water than conventional fixtures. Ultra low flush toilets can save 18,000 to 26,000 gal/year for

an average household. Composting toilets can save even more water. For older model toilets that are neither replaceable nor efficient, toilet dams can save a maximum of 1 gal/flush.

Every western State can use water law as a tool to encourage or require water conservation. Many States have specific statutory authority to run a water conservation program. Every western State prohibits water waste. State plumbing codes exist in many States as do statutory changes to facilitate water transfers, water marketing, rights to salvaged water, surface water banks, groundwater recharge, etc. Several western States have also been given authority to require local conservation plans.

Potential Benefits and Problems

Efficient water use can result in significant benefits. Water conservation can extend short supplies in emergencies, and reduce demand or increase supply during droughts or dry years.

Reductions in water use can result in significant energy savings. Water heaters are the second largest energy users in residences, exceeded only by heating and air-conditioning systems. Hot water use can be reduced almost one-third by cost-effective fixture retrofits. Reductions in water use can also decrease the energy required to distribute water and to collect and treat wastewater. However, it may need to be investigated whether the higher concentrations of constituents in the wastewater require additional energy consumption for processing.

Efficient water use can create savings of capital expenditures because of deferred, downsized, or eliminated water supply projects. Conserving water in residences and reducing process uses by commercial and industrial users decreases wastewater flow volume. This saves pumping energy and chemicals. Also, the capacity of certain wastewater treatment plant process units may not have to be as large, and there may be further savings in the collection system. Efficient water use can reduce degradation of the environment by increasing stream flows and water levels in existing reservoirs and by reducing drawdown of groundwater levels and mining of groundwater basins. Also, when viewed from a social perspective, water savings in urban areas may also produce environmental benefits of having more water for protecting streams, wetlands, and estuaries.

In most communities, increasing water use efficiency results in cost reductions. Costs are lower because of reduced energy and chemical use in water and

wastewater operations; further reductions may be observed in the energy costs incurred for water heating and other power uses. Another benefit is compliance with certain regulations such as those requiring water-efficient plumbing. A final benefit is an *enhanced image in the community as an environmentally-responsible entity*.

Water conservation opportunities must be evaluated on a case-by-case basis. While conservation has important benefits, there are trade-offs. Certain measures may or may not make economic sense. It is also important to note that many benefits may be difficult or impossible to quantify economically. Environmental benefits of water conservation, such as increased instream flows and improved fish and wildlife habitat, are important. However, the opposite is also possible, as water conservation may impose important environmental costs. Conservation can lead to a loss of irrigated or other wetlands, reduced groundwater recharge, and reduced streamflows in certain river reaches. At the State or regional level, authorities should at least recognize (and may wish to attempt to avoid or mitigate) such negative impacts.

Other potential problems also exist with water conservation. Water conservation may postpone dates for new construction of facilities to meet additional capacity demands. This is usually favorable, however, inflation may increase project costs. Also, increasing water use efficiency under normal conditions may make additional savings during a drought more difficult to achieve. It may make it more difficult to cut back use, thus creating more hardship during shortages. On the other hand, wise conservation may actually forestall shortage conditions.

3 Unique Aspects of Army Installations

General

Army and Marine installations differ from the civilian sector in creation of and response to change. Economic factors and population growth in civilian regions and municipalities are often difficult to predict. Municipalities may experience unpredictable growth or decline because of complex interaction of socioeconomic factors. Military installations offer a much more controlled environment dependent on following a master plan that matches population and real property assets to comply with the mission or missions of the installation. As the military is being downsized and missions, personnel, and assets are reassigned and reallocated, this aspect has become somewhat more complex and difficult to predict. National politics, policies, and the effects of Base Realignment and Closure (BRAC) decisions are brought into the picture. Note that this document primarily addresses Army installations. While most of the information contained here applies to Marine installations as well, there may be some differences.

A number of other considerations related to installation water use are:

1. Total service population fluctuates daily because of large numbers of civilian employees who reside off post and commute daily to their jobs on the post. Since these civilians do not reside on base, their per capita water use is significantly less than their military counterparts.
2. The number of consumers also varies with soldier maneuvers and training exercises conducted within and beyond installation boundaries. A possible impact may be hundreds to thousands of Reserve or Army National Guard soldiers arriving for temporary duty during certain periods of the year causing large surges in water service. On the other hand, tenant troop units may deploy for training or emergency situation sites beyond the installation, causing corresponding reductions in total water usage.
3. Army personnel do not pay directly for the water they use, so with limited exceptions, meters have not been used on an individual basis. A recent revision to Army Regulation (AR) 420-49 (Utility Services) now requires operational control meters at each water supply well and surface water source where chemical treatment is required. Additionally, each connection

delivering water to any other installation or government agency is required to be metered. Purchasers of installation water, i.e., civilian communities, are responsible for furnishing, installing, and maintaining meters when the Installation Commander deems it necessary. Major water users on post, such as boiler plants, large industrial users, and housing areas, are to be metered to provide water resource planning data to include reimbursement costs, conservation benefits, and forecasting data. Engineer Technical Letter (ETL) 1110-3-465 covers installation of water meters in new construction.

4. Activities unique to the Army, such as tactical vehicle and aircraft washing and maintenance, significantly affect installation water service and quantity requirements.
5. Army personnel must follow command orders and instructions, implying high acceptance rates via quick enforcement of directives implementing conservation measures.
6. Installations are characterized by their military missions: soldiers and major training centers, logistical production and supply depots, medical centers, or research and development and testing sites. Some installations are dedicated primarily to one of these missions. However, in most cases, there are activities that represent some aspect of all of these missions, with one or two missions dominating.
7. Installation real property (all buildings and acreage) is Army owned, being operated and maintained by the Directorate of Engineering and Housing (DEH) and more recently the Directorate of Public Works (DPW) on behalf of the Installation Commander. Procedurally the DPW recommends to the Commander actions for improving the efficiency and capability of support on a continuing basis. A Commander's decision to implement recommendations, such as water conservation measures, is communicated as a directive, and if it involves water reduction, plumbing fixtures, or education programs, the DPW will comply throughout the installation. The reciprocal also holds, in that a Commander's decision not to conserve (e.g., not to limit irrigation of common areas such as parade and athletic fields and other large grassed areas) is also carried out.
8. Installations are designed to support the activities related to their military mission. The size and activity level of various training areas, vehicle and aircraft maintenance complexes, family and soldier housing, community buildings, and other building categories are surrogates representative of both the population size and mission activities of the installation. As such, allocated buildings, their sizes, and their numbers symbolize places where people use water and how water is used.
9. Utility conservation in the Army focuses on reducing energy consumption, and includes water conservation. For example, low-flow showerheads have been

installed on some posts to reduce the energy costs of boilers or water heaters. The only formal water conservation policy is the requirements of the EPAct.

10. There is a major difference between water demand forecasting for military installations and that of the civilian sector. The price of water, the income of the consumer, and other economic variables are not applicable to projecting water requirements on military installations, since most of the actual users of water do not directly pay for a metered level of consumption. Thus, water-forecasting models for the military are not econometric "demand" models, but are called "future requirement models" (or "water requirement models"), since the model is used to forecast the water required to achieve the mission of the installation. The similarity between water requirement models and water demand models is that the mission-related activities of a military base may closely parallel those of the civilian commercial and industrial sectors, and that both predict future water needs in these sectors.

Water Meters

Stephens and Johnston (1993) suggest universal metering, based on anecdotal evidence in British Columbia, can result in a 20 percent savings in water consumption. Meters have the following abilities applicable to military bases:

1. *Water conservation.* It is possible to compel consumers to consume less water through volumetric charges. The saved water may allow extension of service, improvement of service standards and environmental protection.
2. *Cost recovery and soundness of the water supplier.* By having controls on where water is distributed, a water provider is able to justify appropriate revenue for all expenses and determine provision for future investments.
3. *Unaccounted for water reduction* (clandestine connections and leakages) can be monitored through better information on consumption.
4. *Peak demand abatement.* Cut down on uses that are not indispensable, or even provide the possibility of seasonal or hourly tariffs.
5. *Better data about demands and variations to improve operations and planning of systems.*

Army installations rarely have water meters to measure water use at individual buildings. Tenant activities that receive water and/or wastewater service from the Directorate of Public Works will pay a regular water bill. This would include not only commercial enterprises such as restaurants, banks, convenience stores, etc., but also tenants such as a National Guard site on a large troop base or another DOD unit stationed on a post. Some installations may also have large meters recording

flow into a group of residential houses for the purpose of getting a rough idea of how much water is consumed. New construction is required to have water meters installed. However, there are often no provisions to read the meter to obtain data.

In general, there are no individual meters in Army facilities, family housing, barracks, administrative buildings, etc. This means that the residents have no financial incentive to report or fix leaks in appliances or appurtenances present in their quarters. The Army Chief of Staff for Installation Management (ACSIM) recently determined that there will be no metering of family housing in the near future.

Another unique aspect of Army installations related to water use can be over-sized distribution systems or facilities. Many of the facilities and distribution systems, especially at industrial installations, were designed for uses much heavier than that currently used. For example, an Army ammunition plant was typically designed with the capability to operate multiple production shifts a day throughout the year. Now, they operate for a small fraction of the capability with many buildings and production lines mothballed or similarly inactive, yet they maintain the distribution system. Keeping such a large capacity system capable of providing high quality water can result in excess unaccounted for water compared to the consumption that will take place.

Many Army installations have contracts in effect. Such contracts may need to be reviewed to detect opportunities to use water conservation opportunities especially when a contractor is being paid by the amount of water processed, with no incentive for water conservation. Language in contract documents should help create a water efficient environment. For example, a new technology might help a contractor treat wastewater more cost effectively. However, unless there is a cost incentive to encourage the contractor to adopt the new technology, the contractor is likely to treat the wastewater the old way, and simply pass the cost to the Government for reimbursement. Suppose a contractor processes 5 million gal/day of industrial wastewater and bills the Government $X/gal (use $3.00 per 1000 gal as an example plus their 10 percent profit) for the wastewater and receive reimbursement from the government. If the amount of industrial wastewater they process is reduced, they receive less money in reimbursement and therefore less profit. A 20 percent reduction would mean the loss of $300 per day. In such a case, there is no incentive to conserve water. Another example might be the area of irrigation contracting where a contractor is paid to irrigate so much turf 3 days a week for x hours. Provisions need to be made during contract review to allow the contractor not to be required to water the turf when it is not necessary.

4 Water Conservation Opportunities

This chapter will briefly describe some of the information that leads toward a sound basis for implementation of water conservation opportunities.

Consumers often have little idea of how much water they use or even what kind of toilet they have in their residence. O'Grady and DeWitt (1993) discuss a survey of water users in Phoenix. Respondents were asked how much water they thought their household used per day. The average response was 182 gal. The actual use was over 450 gal per day indicating that respondents seriously underestimated their water use. As part of the same survey, respondents were asked how many of their toilets were ultra low flush. Of the 170 respondents indicating they had one or more, when asked if they used 1.6 gal per flush 86 responded yes while 71 did not know. Similar information was obtained in response to low-flow showerhead questions. This type of information helps to: (1) justify the need for education of residents about water conservation and (2) indicate that the best way to achieve a water-efficient endpoint is to have it be as nearly fail-safe as possible. For example, install ultra-low flush toilets in a residence instead of relying on residents to make behavioral changes in flushing patterns such as for dual-flush retrofit devices.

Water-Related Costs

Understanding the true cost of water is key. The cost of water is often more than just the water bill itself. Associated costs often exceed the cost of water itself, and can include wastewater disposal, energy (for heating, pumping and treating the water), and pretreatment for some wastewater discharges to the sewer. Sewer charges are often based or calculated on metered water consumption and therefore a reduction in water use will automatically result in wastewater service charge savings. This will not necessarily apply to individual residents on an installation, but may apply to tenant activities or to the installation itself if wastewater service is supplied from a nearby community.

A knowledge of the price paid for water is essential. Many different rate structures exist. An installation may purchase water at a flat rate, where the cost per unit does not vary with consumption. Other utilities may have increasing rates in which

the per unit cost increases with larger quantities. Table 1 lists some example charges to heat water, assuming a water source of 60 °F.

Table 1. Cost to heat water.

	Cost per 1000 gal		
Heated Water (°F)	Electricity	Natural Gas	Heating Oil
120	11.00	2.63	3.00
140	14.66	3.50	4.00
160	18.32	4.38	5.00
180	21.98	5.25	6.00

Note: Costs based on unit prices of $.09 per kWh, $0.042 per therm, and $4.80 per MBtu of heating oil.

Small flows can add up over time. A continuous flow of 1 gal/minute may waste 525,600 gal in 1 year, costing several thousand dollars. Figure 2 shows the effects of a dripping faucet. Figure 2 quantifies water loss from leaks of various sizes in a water distribution system.

Demand Management

Lahage (1993) discusses demand side management for water as a viable alternative to development of major sources of supply. Reliability of water savings achieved through demand management is largely a function of program design and implementation. Although demand management uses many of the techniques employed to achieve immediate reductions in water usage during periods of drought and other supply emergencies, its programmatic focus and scope varies in significant ways from short term emergency programs. It can achieve efficiency in all areas of water use: residential, commercial, industrial, institutional, and system use.

Demand management focuses on implementing measures that require few behavioral changes over time by the user. For example, programs targeting reductions in indoor house-hold usage generally include measures to accelerate installation of water saving fixtures in households. Reductions of 8 to 10 percent of indoor household use can be achieved through retrofit alone (showerheads, aerators, toilet retrofits, etc.) (Lahage 1993).

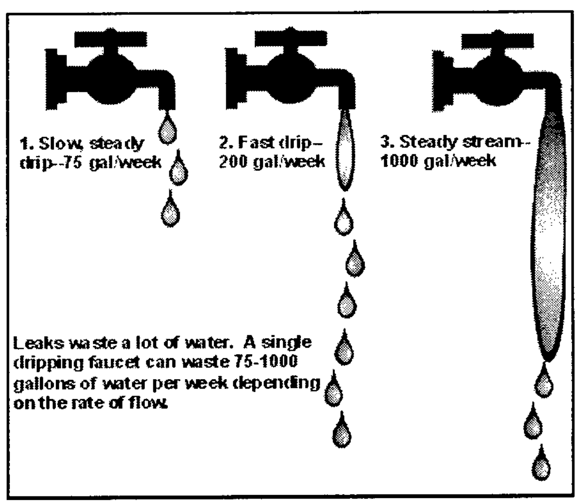

Figure 1. Water loss from leaks of various sizes.

WATER LOSS IN GALLONS

Leak this Size	Loss per Day	Loss per Month	Loss per Year
•	120	3,600	43,800
•	360	10,800	131,400
•	693	20,790	252,945
•	1,200	36,000	438,000
●	1,920	57,600	700,800
●	3,096	92,880	1,130,040
●	4,296	128,880	1,568,040
●	6,640	199,200	2,423,600
●	6,984	209,520	2,549,160
●	8,424	252,720	3,074,760
●	9,888	296,640	3,609,120
●	11,324	339,720	4,133,260
●	12,720	381,600	4,642,800
●	14,952	448,560	5,457,480

Figure 2. Water loss (gal) for leaks of various sizes.

Industrial, commercial, and institutional users can be encouraged to accelerate use of water saving technologies and maintenance practices to reduce cooling, process, and sanitary usage. Substantial savings can occur through new applications of existing technology, implementation of strategies to maximize reuse and recirculation, and improved maintenance practices. Simple changes in equipment, fixtures and maintenance routines were found to reduce water use by 10 to 25 percent for businesses with paybacks under 3 years. Leak detection and repair on a biannual basis can also be a key component of a demand management program.

Dziegielewski et al. (1993) discuss demand-side management related to water planning. Demand management has developed models of increasing complexity that may help planners. To develop demand management programs, a planner must become familiar with types and patterns within the service area through a knowledge historical and current uses of water. High levels of disaggregation can reveal detailed data to project future water demands. Demand management programs must be viewed as one among many types of factors known to influence urban water demands. Among all the influencing factors, it is helpful to distinguish those that influence the average rates of water use. The drivers of demand (such as the number of residents, housing units or employees) are determined by natural birth rates, net migration, family formation rates, labor participation rates, urban growth policies, the rates of economic growth, and the levels of economic output. The average rates of water use in homogeneous sectors of water customers (such as per person, per household or per employee use) are determined by such influencing factors as air temperature and precipitation, household income, household size and composition, housing density (or average parcel size), levels of efficiency in water use, prices paid for water service and wastewater disposal, industrial productivity, and other variables.

Interaction effects (Dziegielewski et al. 1993) exist when conservation programs are subsequently applying percentage reductions in time in water use to an already decreased amount of water use. The reductions from previous programs would thereby limit the reductions from subsequent programs. Measuring effectiveness of programs consequently becomes less accurate as programs are initiated, because the reduction effects of each program are ameliorated by the reduction in customers that have not already been affected by a previous program.

An example of demand management encompassing several approaches at a county level is presented for Palm Beach County (Gleason et al. 1993).

Irrigation Ordinance

An ordinance was enacted that bans residential irrigation between the hours of 0900 and 1700, unless the irrigation system uses treated wastewater effluent.

Xeriscape

The county is implementing a xeriscape program through the County Landscape Ordinance, implemented through the Site Planning Section of the Zoning Department. The Landscape Code requires that 50 percent of the landscape of new development consist of low-water-use native plants. The code specifically addresses "water conservation by encouraging xeriscaping and use of native and drought tolerant landscape material; use of water conserving irrigation practices; adherence to sound landscape installation standards that promote water conservation; ecological placement of landscape material; and use of natural areas and vegetation." This is enforced by the landscape vegetation inspector of the Site Planning Section who has review approval authority over development plans.

Ultra Low Volume Plumbing Fixtures

The County has approved an ultra low volume plumbing fixture ordinance. The ordinance amended the Standard Plumbing Code as part of the minimum construction code for the county and municipalities under review and inspection. The ordinance specifies that the maximum allowable water usage for new plumbing fixtures is 1.6 gal/flush for toilets, 1 gal/flush for urinals, a flow from sink faucets that varies from 0.5 gal/minute to 2.75 gal/minute, and a showerhead flow of not more than 2.5 gal/minute.

The County also adopted a conservation rate structure (inverted block rates), a leak detection program, and a water conservation education program for the public. The Palm Beach County Water Utilities Department (Gleason et al. 1993) found that water meters should be replaced after 15 years due to lack of accuracy. They also found water theft through illegal connections by developers to be a problem and took corrective enforcement action.

Another approach at the local level is presented by Duquette (1993) who discusses water conservation in the town of Henrietta, NY. (Also see Appendix C.) The town adopted the most recent revisions to the New York State Building Code and the New York State Energy Conservation Code, which require the use of water conserving fixtures in all new construction. This is enforced in all applications for Building Permits and notifications have been sent to all customers regarding the new codes

and the advantages to use the water conserving fixtures. In all construction and rehabilitation performed on all public buildings, the new fixtures installed are all water conserving.

Town efforts include informing customers of the advantages of reducing customer water pressures, encouraging the use of hot water pipe insulation and assisting in troubleshooting customer leaks and repairs. This is accomplished by distributing written information on pressure reducing devices, enforcing installation of pressure reducing devices in areas of high pressure, and responding promptly whenever a high meter reading occurs or when a customer complains.

Outdoor water use reduction is controlled and promoted by encouraging the use of water-efficient landscaping in new developments and by allowing no reduction in sewer charges for outdoor water use. Lawn irrigation is banned or regulated during periods of drought.

The town also encourages recycling of water in processes such as manufacturing and heating systems and requires sewer charges based on total metered consumption. This practice is meant to discourage excess water use.

5 Retrofit and New Plumbing Fixtures

Residential

Nechamen, Pacenka, and Liebold (1995) found in a study in New York City that the major leak categories and sources of water waste in residences were toilets (especially leaking flapper valves), showers, bathroom faucets, and kitchen faucets. Other categories (laundry faucets, hot water heaters) were not major contributors. The Army's experience is similar. At one installation, Scholze and Maloney (1994) found that the greatest number of leaks in family housing were in bathroom and kitchen faucets.

Stephens and Johnston (1993) discuss reducing water use with water-saving devices. They mention that 70 percent of household water use is in the bathroom indicating that retrofitting with water saving devices offers excellent potential for reducing bathroom water use. One problem with these devices, however, is the probability that a significant proportion of homeowners will remove the devices soon after installation. Therefore, installation of ultra low flow toilets, showerheads, and faucets is the only way to guarantee reduced levels of indoor water use in the long term. These devices should be of high quality.

Effectiveness of retrofits for family housing has been established in a number of studies in municipalities. Neighbors et al. (1993) studied residential, retrofit devices in Harris-Galveston, TX. Low-flow showerheads, kitchen aerators, and bathroom aerators were installed in single family residences. Their results, derived by comparing pre-installation months with post-installation months, found an average monthly savings of over 1400 gal or about 18 percent of the average consumption of a residence. Water savings amounted to 14.1 gal/person/day. They also attributed electrical energy savings of about 18.6 kilowatt hours per month to a reduction in hot water heating.

Scott and Prokop (1993) describe a retrofit study in New Jersey. They wanted to determine: (1) the effectiveness of retrofit devices for their customers, (2) what delivery methods yielded the best results for the least cost, (3) what penetration and retention rates could be expected, and (4) the actual water savings that could be expected. Their study included either early closure devices for toilets or toilet dams,

low-flow showerheads, faucet aerators, and leak detection tablets. Results of the portion of the study where homeowners installed devices indicate that 18 percent were dissatisfied with the toilet dams compared to 30 percent who were dissatisfied with the early closure device. Thirty-six percent of the customers did not install any toilet device or removed it later. Sixteen percent of the customers were dissatisfied with the low flow showerheads, and 32 percent either did not install them or removed them later. A group of 400 customers volunteered to have a contractor install devices. However, only 69 percent of these actually participated. Thirty-five percent of that group were not satisfied with the toilet devices and 26 percent were not satisfied with the low flow showerheads. Analysis of savings showed participants reduced winter water consumption 3.0 percent for the retrofit program in which homeowners installed the devices, and 6.5 percent for the retrofit program in which contractors installed the devices, using a pre- and post-conservation method of analysis.

Martin (1993) reviews a survey of purchaser opinions on ultra-low flush toilets in Los Angeles. Responses represented over 31,000 ULF installations. Generally, ULF purchasers were well satisfied with their new toilets. Seventy-five percent said they would "very likely" purchase ULF toilets in the future. Only 7 percent said they would very likely purchase conventional toilets in the future. Overall satisfaction ratings were also found to be high. Individual models were also rated.

A recent review of a New York City program for residential water conservation (Nechamen, Pacenka, and Liebold 1995) found that a variety of options should be available for retrofitting toilets. Displacement bags for toilets were found not to be the best choice for many toilets as many toilets had leaking flapper valves. The contractor was given a wider choice of retrofit alternatives including fill-line diverters and "early closure" flapper valves.

Walker (1995) describes a Canadian ULF replacement program where ULF toilets and water-efficient showerheads were installed. There were 20 and 22 percent reductions in water use in two datasets of households from two towns and a 41 percent reduction in apartment water consumption from one multi-apartment complex. Eighty percent of the residents were more than satisfied with their low flush toilets and they had reduced water bills.

Mulville-Friel et al. (1995) discuss the city of Tampa's ultra low volume (ULV) toilet rebate program. They found an approximate 38 gal/house/day (15 percent) reduction in water use by replacing conventional toilets with ULV equivalents. They also found that the ULV toilets consistently rated as well as or better than their

conventional toilet counterparts in the areas of double flushing, clogging of toilet bowl, toilet bowl cleanliness, and mechanical problems.

Nero and Mulville-Friel (1993) discuss impact of water conserving plumbing fixtures at a school and in multi-family housing in Tampa, FL. The school had significant leaks in many faucets and urinals. Background data was established. The leaks were corrected and spring-loaded, self-closing faucets installed before establishing a baseline. After establishing a baseline, 30 of the existing 40 toilets were replaced with 1.6 gal/flush flushometer type toilet. Water use changed from 2.94 gal/student/day during the first phase to 2.14 gal/student/day following urinal repair and installation of self-closing faucets to 1.45 gal/student/day following the ultralow volume toilets, a total reduction 53 percent, 29 percent attributable to leak repair and installation of the self-closing faucets. User acceptance of the toilets was excellent although maintenance staff reported the self-closing faucets were easily disabled by students and there was dissatisfaction with the inability to easily wash hands because of the constant requirement to have pressure in the faucet handle.

The apartment retrofit resulted in a 17 percent reduction in water use from installation of low flow showerheads and low flow toilets from 3.6 gpf to 1.6 gpf (Nero and Mulville-Friel 1993).

Nonresidential Applications

Mariscal and Bamezai (1995) discuss ultra low flush toilets in institutional settings. A study found an average water savings per toilet of 76.8 gal/day from retrofits. However, one should be cautioned that applying this factor to all institutional settings can be misleading. Considerable variation in level of savings may be achieved from public sites (Figure 3). The “Other” category included recreation centers, senior centers, pools, comfort stations, etc. where an average water savings of 116.8 gpd was registered. In comparison, an average water savings of 20.5 gpd/toilet was achieved under the “Police” facility category. Key predictors of savings include: number of toilets and urinals present, number of full-time employees and visitors and respective genders, amount of time spent at the facility; hours and days of operation; and flushing volume of existing toilets.

Blease, Georgopoulos, and Gauley (1995) discuss an Ultra Low Flush performance evaluation in Toronto non residential buildings. They used retrofitted water closets as the control group where the retrofit involved cleaning the rim holes of scale or excess glazing, installing an early closing flapper, and adjusting the unit to flush properly. The toilets were lowered from a pre-retrofit flush volume of 20.9 L/flush

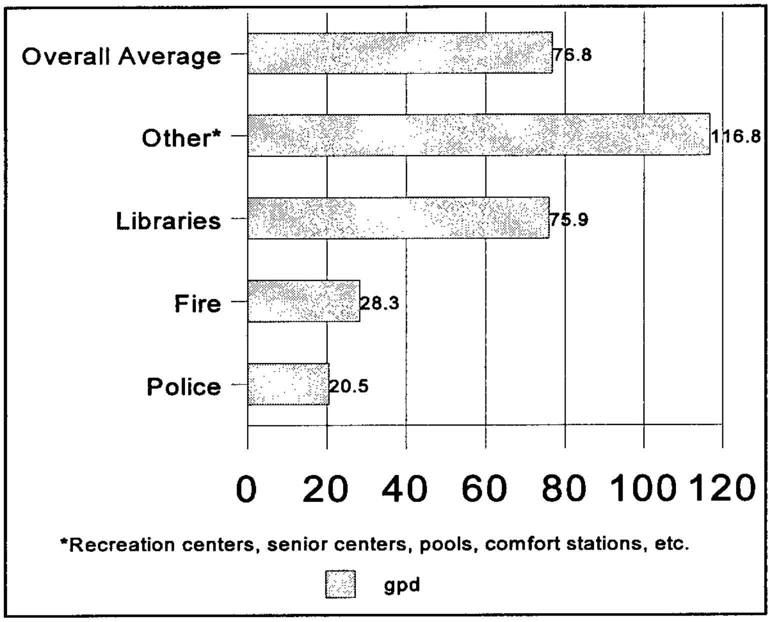

Figure 3. Average water savings per toilet, per facility type (gpd).

to 14.6 L/flush. ULF fixtures were also installed. Interesting findings were that, for the five manufacturers chosen, the ULF units did not satisfactorily flush at 6.0 L (the Ontario Building Codes' maximum allowable flush) in nonresidential buildings and required adjustment to 7.9 L for proper flushing. That was still substantially better than the retrofitted water closets. They also found that the age of a building and its use needs to be taken into account when deciding which type of water closet should be selected. It appears that the more hostile the environment, the greater the flush volume should be. They have also found that where practical, flush valve water closets should be used in nonresidential buildings if a 6-L flush is required.

Guidance

Many options are available for minimizing water demand for domestic uses, from retrofitting with inexpensive devices such as faucet flow restrictors, flow restricting orifices in showerheads, toilet dams (or tank displacement bags), or flush reduction devices for flush valve operated toilets; to replacing fixtures with low-flow units, spring or infrared actuated faucet valves, or replacing showerheads with reduced flow units. Regular maintenance is especially important in this area. A scheduled program of leak detection and repair can provide considerable savings in water and energy costs for a small increase in maintenance effort, particularly at larger and older facilities.

Water efficiency measures can be applied to domestic uses including toilets, urinals, lavatory faucets, and showers. Plumbing codes require all new fixtures to be of the ultra-low flow type. Appendix D includes plumbing fixture efficiency standards enacted by Congress in 1992 and some State standards. All toilets manufactured after 1 January 1994 are required to meet a 1.6 gpf standard.

Many options are available to improve water efficiency of plumbing at existing residences and facilities (single-family, multi-family, barracks, administrative, commercial, etc.). Possible water efficiency measures range from retrofitting fixtures with inexpensive devices, to entirely replacing the fixtures with low-flow units as indicated with the earlier discussions.

It is important to use high quality devices: devices that do not deliver a good shower or cause extra labor (i.e., dual-flush mechanisms) by the user will often soon be removed or disabled. If a device provides good service and can be made "people-proof," it has a better chance of being accepted and remaining in use.

Decisions will have to be made by the responsible party as to when to retrofit or install new fixtures. Paybacks are often less than 1 year. However, an examination of what is planned for the facility along with an installation's budget and master plan will drive appropriate action. For example, it does not make any sense to retrofit family housing with ULF toilets when the units will be demolished within a short time span. However, faucet aerators, toilet dams, or low-flow showerheads would be a viable option.

Toilets

The following discussion addresses residential and nonresidential domestic usage.

There are three basic types of toilets: flushometer valve type, tank type, and pressurized tank systems. A flushometer valve, the more common type in public and commercial settings, includes a diaphragm valve that is opened to let in a rapid stream of water at full line pressure. In a tank toilet, which is the type most commonly found in residential settings, flush water is stored in the tank and released for flushing by the lifting of a flapper valve in the tank.

Toilets and urinals equipped with flush valves can be retrofitted with orifice inserts or valve replacement kits to reduce the volume of water used per flush. Certain more recent flush valves have reversible rings inside, which, when turned over and

reinstalled, will reduce the flushing volume. Periodic replacement of diaphragm or worn parts should take place.

Consider replacing existing toilets and urinals with new ultra-low flush (ULF) models. ULF toilets use 1.6 gal/flush or less; ULF urinals use 1 gal/flush or less. Only ULF toilets and urinals may be used in new construction. These units are the only way to achieve rates of 1.6 gpf. Retrofits cannot achieve these types of savings.

Tank-type toilets should be dye-tested once every 6 months to check for leaks and leaks should be repaired. (Periodically valves and ballcocks should be replaced.)

A variety of retrofit options are available for gravity tank-type toilets that are effective to varying degrees in lowering consumption rates, particularly of the 5 gpf models. Most of the retrofits cost under $20 and improve the water efficiency of the toilet. These retrofits, however, may hamper the overall operation of the toilet and increase maintenance costs, as they often have a short life span and require frequent replacement or adjustment. Therefore, they may not be appropriate for Army facilities. A list of devices follows:

- Displacement devices, such as bags or bottles, are designed to displace or reduce water flow by approximately 0.75 gpf. These devices are inexpensive and are relatively easy to install in tanks. Like most retrofit options, they require regular maintenance.

- Toilet dams are flexible inserts placed in a toilet tank that keep a limited amount of water (0.5 to 1.0 gpf/dam) out of the flush cycle. Dams can be used in pairs in large tanks to save even more water, and can last for as long as 5 to 6 years. Because occasional difficulties are encountered while installing toilet dams, you may wish to consult a plumber before you begin retrofitting.

- Early closure devices replace or amend the existing flush valve in the tank, using the original amount of pressure to exert the same force in the flush, but with less water. These devices save 1 to 2 gpf.

- Dual-flush adapters adjust the system to use two flushes, saving as much as 0.6 to 1.2 gpf. One flush is standard and discharges solids from the bowl, while the second, smaller flush, removes liquids and paper. With this retrofit, however, it is important that users be taught how to operate the equipment properly and that signs be installed in restrooms to remind users of the procedure. These type of devices are not recommended for use in Army facilities.

Flush valve toilet retrofit options exist that can lower the consumption rates of the 5.0 gpf models.

- The most effective, and also most expensive retrofit for flush valve toilets is the installation of electronic sensors. These sensors automatically activate flushing, making it unwieldy for people to flush twice.

- Two types of electronic sensors exist:

  - *Infrared sensors* emit an infrared light beam to detect motion. The beam is broken first when an individual sits on the toilet, and again when the individual rises, activating the toilet flush. The sensor is specifically designed not to detect passersby and automatically resets itself after each use.
  - *Ultrasonic sensors* function similarly to an infrared sensor, but use high-frequency sound waves to detect motion.

Pressurized tank system toilets, the third type of toilet, was specifically designed to use 1.6 gpf. They are the most modern and effective toilets on the market and the most popular replacement for gravity toilets. In this toilet, a pocket of air in the tank exerts pressure on the water. Pressure is maintained until the flush valve is released. Release of the flush valve forces the pressurized water down into the bowl at a force 500 times greater than the conventional 5 gpf gravity toilets.

For commercial applications, a "blowout" toilet, similar to the pressurized tank system in terms of water efficiency and disposal, is available. In this toilet, the pressurized tank is located behind a wall.

To ensure peak performance of these toilets it is important to check regularly for leaks.

Common Urinals

Most urinals in use today consume 2 to 3 gpf. To comply with recent Federal guidance, all new urinals use no more than 1 gpf.

Urinals are manufactured primarily as floor-mounted or wall-mounted, in a number of sizes and shapes. The wall-mounted models are the most popular because of the advantages they offer in both cleaning and maintenance.

As with toilets, flushing is traditionally accomplished by means of a flush valve, water tank, or, in the case of trough urinals, by a washdown pipe assembly that provides a continuous or intermittent flow of a regulated volume of water.

Siphonic Jet Urinal

The most common type of urinal is a siphonic jet urinal. These urinals have been designed to accommodate greater levels of traffic. These urinals have elevated flush tanks and actually provide a flushing action capable of removing foreign matter. They operate through the use of a siphon device, which automatically discharges the tank's contents when the water level in the tank reaches a certain height.

These urinals are more sanitary than washout urinals in that they provide for a periodic cleansing of the urinal without the need for user assistance. They also require less maintenance in that they do not contain a flushing mechanism that can be easily broken or vandalized. Their primary disadvantage is that water flows through them constantly — day and night, every day of the year. Water efficiency modifications for these urinals follows.

Maintenance Modifications. Check regularly for leaks (every 6 months); periodically check the pin hole and rubber diaphragm, and replace the diaphragm if necessary.

Retrofit Options.

Adjust/retrofit flushometer valves. Existing flushometer valves can be fitted with water-conserving parts that reduce the water consumption in the valve, as long as these adjustments meet the flushometer and fixture manufacturer's recommendations.

Use a timer. A timer can be used to control the removal of wastes that collect over time as a result of multiple uses. To eliminate water waste created from a urinal that flushes a small amount of water periodically, timers can be used to stop the flow of water when the building is not occupied.

Replacement Options. Replace with models that have been designed to operate with only 1 gpf. A wide variety of models is currently on the market.

Washout and Washdown Urinals

In a washout or washdown urinal, water trickles into the basin and is washed out of the basin and down the pipes using a mechanical or push-button handle. These urinals are intended to remove liquid wastes only and are most commonly found in low-use areas. Water efficiency modifications for these urinals follow.

Maintenance Modifications. Check regularly for leaks (every 6 months)

Retrofit Options. Urinals can be fitted with infrared or ultrasound sensor-activated controls that automatically flush after the urinal is used.

Replacement Options. Replace with models that have been designed to operate with only 1 gpf.

Blowout Urinal

Blowout urinals are most commonly found in areas of high traffic, such as airports or sports arenas. These urinals consist of an elevated flush tank located behind a wall in back of the urinal. Similar to siphonic jet urinal, when the waste and water level reaches a specific height in the tank, a hydraulic flushing mechanism automatically empties the tank contents (including foreign matter).

Maintenance Modifications. Check regularly for leaks (every 6 months).

Replacement Options. Install timers or sensors to operate urinals only when the building is occupied.

Waterless Urinals. A fairly recent but rapidly achieving acceptance device on the market is the waterless urinal. These devices have the ability to substantially reduce quantities of water required in a barracks, office, or similar setting. They look like a conventional urinal, however, urine passes through a liquid air seal into the plumbing infrastructure.

Faucets

Tremendous amounts of water are wasted using conventional faucets with typical flow rates of 3 to 5 gpm. In fact, a leaky faucet at one drip/second, can waste about 36 gal of water/day.

Reduced use of hot water by faucets will result in energy savings as well as water/sewer savings. Often, the financial value of the energy savings is even greater than the financial value of the water savings.

Federal guidelines mandate that all lavatory and kitchen faucet and replacement aerators manufactured after 1 January 1994, consume no more than 2.5 gpm, measured at 80 psi. Metered valve faucets are limited to 0.25 gal/cycle.

Retrofit faucets with aerators to add air to the flow stream and reduce water usage. Many faucets with aerators consume as little as 1.0 gpm. Tamper-proof aerators are available and should be used at sites where vandalism is a potential problem (for example, schools).

Traditional Type: Manual Valves

Most older faucet fixtures are hand-operated and have typical flow rates of 3 to 5 gpm. For a very low cost, there are a variety of options to help reduce their use of water.

Operation Modifications. Adjust the flow valve to reduce water flow.

Maintenance Modifications. Check regularly for leaks.

Retrofit Options. Flow restrictors, like those used in showerheads, limit the maximum flow rate to a range of 0.5 to 2.5 gpm through a washerlike disk installed in the faucet head. Aerators, in the form of a head placed on top of your faucet head, add air to the flow stream, increasing the effectiveness of the flow and requiring less water.

Replacement Options. Faucets can be replaced by alternative faucets that control the duration of flow and prevent water from running when not in use. Buildings with heavy traffic are particularly appropriate for these faucets, for example, schools, theaters, museums, airport terminals, public buildings. Three types of faucets can be considered: metering faucets (which stay open a pre-set period of time and then close), self-closing faucets (which close as soon as the user releases the knob), and automatic sensor-controlled faucets. One of the disadvantages of metering faucets is that accumulated sediment can interfere with the workings of the spring-loaded closing device. The result is that the faucet can actually stay on longer than is necessary. Metering faucets should be checked periodically to be sure they are closing properly.

Low-Flow Type: Metered Valves

Metered valve faucets deliver a preset amount of water and gradually shut off.

Operation Modifications. Adjust the flow valve to reduce water flow.

Maintenance Modifications. Check regularly for leaks.

Low-Flow Type: Self-Closing

The self-closing faucet is spring-loaded to shut off a few seconds after the user triggers it.

Operation Modifications. Adjust the flow valve to reduce water flow.

Maintenance Modifications. Check regularly for leaks.

Low-Flow Type: Infrared and Ultrasonic Sensors

Sensors located in the faucet head activate the water flow when they detect the presence of an individual's hands or some other object beneath the faucet. When the hands are taken away, the flow is immediately cut of. These sensors automatically reset after each use, and are designed to not be activated by passersby.

Operation Modifications. Adjust flow valve to reduce water flow.

Maintenance Modifications. Check regularly for leaks. Check regularly to ensure that the flow controller connected to sensor does not become clogged with impurities carried by water. If necessary, consider filtering water before it reaches the faucet.

Showerheads

Most existing showerheads consume more water than necessary under normal operating conditions. For example, a 5-minute shower using a conventional showerhead may consume between 25 to 35 gal of water. A conventional showerhead typically uses from 3 to 7 gpm of water at normal pressure.

Water efficiency measures for showerheads will result in energy savings as well, and therefore additional cost reductions:

- Encourage users to take shorter showers.
- Adjust the flow valve to reduce water flow.
- Lower the setting of the hot water temperature.
- Check regularly for leaks.

Retrofit Options

One option not recommended for Army application is the use of flow restrictors. They are presented here for completeness. Flow restrictors, washerlike disks that fit inside a showerhead, limit the waterflow. At less than $5 each, they are one of the most cost-effective options available. Early designs for these restrictors were noisy at higher pressures. Such noises are uncommon with the newer high-quality products. They provide poor shower quality and the cost for complete replacement with a new low-flow shower head is relatively low.

Temporary cutoff valves, usually attached or incorporated into a showerhead, cut off the water while an individual is soaping or shampooing. The water is then reactivated at the previous temperature, eliminating the need to remix the hot and cold water.

A consistent problem with the cutoff valve, however, is that often water is not reactivated at the previous temperature. Many times, the reactivated water is hot and may possibly burn the unsuspected individual showering. Given the potential for burning, this may not be the best retrofit for a facility. However, if this option is selected, warning signs should be posted urging individuals to exercise caution.

Replacement Options

The following replacement options maintain shower quality and achieve the 2.5-gpm requirement for all new showerhead fixtures. These products typically vary in price from $3 to $95.

These showerheads were specifically designed to conserve water. They have a narrower spray area and a greater mix of air and water than conventional showerheads. These features enable them to decrease the overall water consumption and at the same time provide what feels like a high-volume shower. They will also save energy by reducing hot water consumption. Several new models and their features include:

1. Atomizer showerheads, which deliver water in small but plentiful droplets that wet larger surface areas
2. Pulsaters, which vary the spray patterns with a flow that pauses between spurts or through intermittent strong flow and light mist
3. Aerators, which mix air with fine water droplets to wet more surface area.

If barracks, gymnasiums, or similar facilities have one valve operating several showers at once, individual valves should be installed on showers.

6 Water Distribution System Programs

A water supplier or purveyor can take a number of actions in support of a water conservation program or to save water. Included are such actions as a leak detection and reduction/repair program, installation of water meters, and the addressing of unaccounted for water.

Leak Reduction

The classic definition of unaccounted-for water (UFW) is the difference between what you pump and what is billed, normally expressed as a percentage. This amount is not all leakage. The basic components of UFW are: nonsurfacing leakage, metering error, water lost during leaks and breaks (surfacing), inoperative controls, street cleaning, hydrant flushing, fire fighting, water used in flushing water mains or sewers, other authorized unmetered uses, and illegal connections.

"Leakage" generally accounts for about one-third of the total UFW picture (Clementi et al. 1995). This recoverable, nonsurfacing leakage is what should be discovered and repaired.

An opportunity to reduce UFW can begin at the water treatment plant. Backwashing at any surface water treatment plant has a potential for significant water savings and increased production time if the backwash rate and time are optimized. Generally, operators tend to backwash too long. One company found that high rate backwash times could be reduced from over 10 minutes to 5 minutes and could reduce water usage from 107,000 to 69,000 gal/wash (Clementi et al. 1995).

To decide whether a leak detection and repair program is justified, an installation should conduct a water loss survey. Procedures have been outlined in Army materials (U.S. Army Construction Engineering Research Laboratories (CERL) Technical Report (TR) N-86/05 and U.S. Army Center for Public Works (USACPW) TN 420-46-02). This will divide unaccounted for water into two categories, authorized and unauthorized uses.

The critical step in a preliminary water loss survey evaluation is to determine whether a leak detection and repair program will be cost-effective. This analysis must take into account all direct and indirect costs. Costs to repair leaks will vary with the extent of the problem. Benefits show up in several ways. There are the reduced costs for purchase, treatment, and distribution of water, plus expansion of water treatment and storage facilities may not be needed as soon. Another benefit is reduced liability due to prevention of property damages, i.e., small leaks lead to big catastrophic leaks.

A comprehensive approach to examining water use at a facility or installation is called a water audit. Individual representative uses are measured, records examined, etc., to build a complete picture of where and how water is used on the installation/facility. It can be performed in-house through a support agency such as USACERL, USACPW, or NAVFAC, or through a contractor. Additional information is in Chapter 16.

Leak Detection Methods

Leaks that surface are easy to find because water is present at the ground surface although the water may not surface near the pipe break. However, many leaks do not surface and can go unreported indefinitely. All leaks make noise. Leak detection equipment detects noise through amplification of sound at contact points such as water meters, hydrants, and valves. Sonic computer correlation equipment has the ability to pinpoint leaks within a few feet.

The best way to reduce leaks is to prevent their occurrence. Proper main design and installation are essential. Poor bedding is often a cause of breaks. A corrosion control program can prevent external corrosion, another leak source. Other maintenance techniques include meter maintenance and valve exercising. Pipes should be relined or replaced when they are in poor condition.

Other options at the treatment plant level are water use audit, staff education, master meter accuracy, and meter calibration.

In a study conducted by a large water utility, production meter errors varied from 0.1 to 24.5 percent, indicating that 2 to 3 percent of their total UFW was known metering error (Clementi et al. 1995). They also initiated a policy of "sounding" (detecting noise through amplification of sound at contact points) every hydrant, valve, and curb stop as they are operated, serviced, or inspected to more readily detect leaks before main failures.

Leak repair allows less water to be pumped, with less consequent wear and tear on equipment. Approximately 1 to 2 percent of total water production goes for uses such as fire department drilling and fire fighting, unmetered watering of parks, etc. A comparison of reported inactive services with field data should be conducted. Take advantage of data that can be easily collected. If flow tests are done, record amounts, if you have Supervisory Control and Data Acquisition (SCADA), quantify water lost during leak events. There are easy methods to estimate field use of water during flushing. Map leaks and breaks to identify high intensity failure areas. Clement et al. were able to derive a benefit-to-cost ratio of 2:1 for cutting down their UFW leakage component.

Finn (1995) presents a multidisciplinary approach addressing the problem of unaccounted for water. Problems of water and associated revenue losses can most effectively be addressed when identification and quantification of losses are determined. The more accurate the quantification, the better the ability of the remedial approach. The approach taken at one utility addressees the following activities:

1. Updating system maps
2. Comprehensive meter testing
3. Verifying and quantifying metered use records, such as billing and accounting information, unmetered use records, estimates of water used for flushing, fire fighting, etc.
4. Evaluating meters and usage for proper sizing
5. Field checking for transmission and distribution main and service leaks
6. Field checking for hydrant and valve leaks
7. Identifying theft or other unauthorized water uses.

Benefits of the program include:

1. More accurate quantification of water delivered into the system
2. Identification of water loss quantities and categories
3. Reduction in revenue losses and improved financial picture
4. Reduction in property damage through improved maintenance, fewer leaks, and repair or replacement of malfunctioning meters.

This type of aggressive approach will involve substantial computer customer analysis and matching of datasets, a leak detection program, review of methodology used in estimating fire hydrant flows, meter testing and evaluation, detailed analysis of billing data, and establishment of procedures for revenue protection.

Military Aspects of Leak Detection

Background

Water in the United States historically has been low cost, compared with the importance of the resource. However, costs and value are both increasing. Military installations are mandated to effect a water conservation ethic by the Energy Policy Act of 1992 and Executive Order 12902.

Another driver for water conservation and specifically leak detection is the financial incentive. Less water used means less energy required to pump, treat, and distribute it. The real cost of lost water can be $6 to $9 per thousand gallons. Also, money is saved because fewer chemicals will be required. Finally, there will be less wastewater to treat.

Military bases have very limited metering, often only tenant activities have meters and are billed by the Directorate of Public Works. There may also be production meters and a few scattered gang meters to capture representative uses on the installation. Military installations do not know the patterns of usage so there is little accountability to end users as they do not receive any feedback, i.e., bills. Therefore, it is essential that a military installation conduct regular leak detection surveys to prevent substantial water losses occurring, unknown to the installation.

Leak Detection Basics

Leak detection is extremely cost-effective, usually with a payback of only a few months. Methods to detect leaks should be the first step in any water conservation program as well as part of the general operation and maintenance procedure for the facility.

Why have leak detection? Early leak detection can save resources. It can prevent loss of valuable potable water and stretch existing supplies. It will also help prevent major breakages via early identification of problems and is useful to minimize expenses.

Water Loss

Water is lost through leaks and breaks. Leaks result from loose joints or service connections, while breaks occur when a water main fractures. Reasons for fracture include structural failure, excessive load, low temperatures, and corrosion.

Sonic Technology

Leaking water has three characteristic sounds, which can be used for locating and pinpointing the leaks. A variety of equipment is used for leak detection. The three most common types are: stethophone, geophone, and aquaphone. Another type of equipment uses computer correlators to compare noise signals detected at sensor points on the pipe under analysis. While the first three categories of equipment are inexpensive (up to hundreds of dollars), correlators are expensive ($20,000 to $30,000) and require significant training for accurate use.

Leak Detection Survey

A major component of the cost of a leak detection survey is the cost of transportation of workers and equipment for nonlocal applications. A rough guideline of what it should cost an installation is from $80 to $140/mile, with the survey type varying in complexity and thoroughness. There can be some economies of scale, i.e., a slight decrease in cost per mile (around $10) when exceeding thresholds of 100 or 1000 miles of pipe.

A leak detection contractor should provide, as a minimum, a record review and analysis to review pump records, energy costs, etc.; determination of unaccounted-for water; updating maps; testing master meters and major consumer meters; an inventory of defects; and providing recommendations for the future along with actually conducting the survey.

During a leak detection survey of the water distribution system, the contractor should do the following: make physical contact with every hydrant, contact at least 50 percent of valves, more if they're farther apart or many leaks are detected. Physical contact should be made every 200 to 300 feet through the system. One approach is to first use the simpler listening equipment to detect evidence of leaks and then use the correlation equipment for locating and pinpointing leaks.

Leak Survey Results

Several military installations have had leak surveys conducted. The portion of the total water supply lost due only to leaks is often 15 to 25 percent of total production. One installation found 435,000 gallons per day (gpd) one year. The following year another 309,000 gpd were found. A third survey 6 years later found 344,000 gpd, wasting $165,000 per year, 15 percent of installation water production. A second base found 128 million gallons per year of wasted water. A third base found 81

million gallons per year, $72,000 at $0.90 per 1000 gallons. A fourth post with 212 miles of water distribution lines found 242 million gallons per year. Significant cost savings—hundreds of thousands of dollars—can be readily found. Leak detection surveys of the distributon system pay for themselves in a few months. Building leak surveys can also be performed. A building survey at one military post indicated that repairing the top 227 leaks would save 6.3 percent of water usage.

Recommendations

It is usually recommended to conduct a comprehensive leak detection survey every 2 years until the system is fairly tight; then the frequency between surveys can be increased. They should be done annually if excessive amounts of leakage are detected. Initiation of a regular valve exercising program should be undertaken. Installation of meters at critical points in the distribution system can provide an early indicator of problems. When a survey is conducted, maps should be updated. Disconnect lines and spurs no longer in use.

Pressure Reduction

Pugh and Samuel (1995) reviewed an initiative titled "Standards and Codes Initiative to Promote Water Conservation" with a goal to expedite the establishment or modification of standards and codes to encourage water efficiency improvements that have a positive impact in the urban area. A number of organizations, entities and government agencies cooperate to accomplish the objectives. One possibility was to evaluate the potential for water conservation resulting from modifying codes to limit the maximum allowable static line pressure for water closets, urinals, and other plumbing products to 55-60 psi. The codes from the major building code organizations in the United States such as ICBO and BOCA currently specify 80 psi as the maximum pressure. Evaluating the water-saving benefits of lowered line pressure merits investigation.

Pressure reduction as a conservation tool is being evaluated by San Antonio (Rose and Neumann 1995). San Antonio is pursuing several studies to evaluate whether water consumption is related to water pressure. City customers are required by code to install pressure reducing valves where the pressure exceeds 80 psi. Low pressure complaints are common below 45 psi, so service levels are operated to ensure a minimum of 45 psi. If the studies confirm consumption is decreased when pressure is reduced, service levels may be realigned to decrease overall operating pressures or customers may be encouraged to install and maintain customer PRV's.

Earlier projects that examined pressure reduction were done in Denver where a 3 to 6 percent decrease in water use was achieved with a 30 psi reduction. Note that it may not be practical for a water utility to significantly reduce water system pressure in existing built-up areas. Such an action may adversely affect firefighting capabilities and customer irrigation systems previously installed at higher pressures. However, new designs for previously unserved areas can be designed to operate at lower pressures, such as 50 psi. Users, on the other hand, may adjust their use time periods to compensate for the reduced flow.

Reclaimed Water

Andrade (1995) examines some perceptions relating to reclaimed water and describes a strong public information/education program to facilitate successful adoption of a residential reuse program. The city of Largo, FL, uses "reclaimed water" to describe tertiary wastewater effluent that is being used for irrigation. Some common inaccurate terms are: graywater or recycled water. These are terms that have specific meanings. For example, graywater is generally the wastewater effluent from nontoilet sources: kitchens, bathroom sinks, tubs, etc., which has lower quantities of fecal coliform. The Largo reclaimed water is of high quality and undergoes extensive treatment before use. He also indicates some advantages reclaimed water has over well and potable water such as: (1) it has no noticeable odor, (2) it has a low salt content, (3) there are no time and day restrictions on watering, (4) there are plant and sod nutrients in the water, and (5) it is much less expensive than water from other sources. Promotion of the environmental benefits of reclaimed water include the fact that it: reduces potable water demand, reduces effluent discharge to surface waters, reduces potential for saltwater intrusion into the aquifer by reducing water demand from groundwater sources, reduces the application rate for fertilizer, and increases aquifer recharge (the water can be directly injected into aquifers for banking). Safety education is another area of emphasis. Color coding is mandatory and a number of nonpermitted uses are identified such as: no hose bibs, no consumption, no interconnection with other sources, no filling of swimming pools, and no piping into residential dwellings.

7 Institutional, Commercial and Industrial

This chapter presents a general overview of nonresidential water use other than irrigation with a focus on the institutional, commercial, and industrial sectors of water use applications. Additional chapters will go into further depth on more Army-specific applications.

Kobrick (1993) discusses nonresidential water conservation. Water use by businesses, industries, and institutions differs from residential use. The most fundamental difference is greater volume per customer, but nonresidential users have far more diverse uses for water than residential customers. An understanding of their needs is required to promote more water efficient management. There is also a variation in water quality requirements from ultra-pure to reclaimed.

Efficient water management is cost-effective. Most nonresidential conservation programs are based on the premise that conserving water is "good business." It can help by reducing overhead expenses, not only by reducing water costs, but potentially the costs of sewage service, chemicals, energy, and other items as well.

Changing business and industrial methods of operation requires a number of concerns be addressed if a water conservation program is to be incorporated into a business or institution or industrial facility not directly responsible to the Directorate of Public Works (Kobrick 1993):

1. *Costs and Profitability*. Facilities cannot be asked to install any conservation measure that costs more than it is worth, or that requires an unreasonably long payback period. In addition to recovering the capital cost of conservation measures, businesses are concerned about changes in their operations that may indirectly harm their profitability.
2. *Changes in Operations*. A facility that already is operating successfully must be shown a good reason to change. Otherwise, their inclination will be, "do not change the recipe."
3. *Product Quality Standards*. In most businesses, quality standards required by customers are increasingly strict. Facilities must be convinced that water-efficient operation does not mean making products of lesser quality.

4. *Capital Budgeting*. In many cases, a facility may be aware of a number of cost-effective plant improvement projects, but has difficulty implementing them, because the plant budget does not include the funds to cover the up-front capital cost.
5. *Perceived Low Priority*. Many large water consumers do not perceive water-related operating costs as significant. The reality in many cases is that water as well as wastewater service is no longer cheap. Managers do not realize that cost-effective water efficiency measures may be implementable at their facility.
6. *Program Credibility*. Businesses and industries may tend to doubt information provided to them from the outside that affects the working of their operations. They may also question whether a conservation program treats them fairly, will result in unwanted interference in their operations, or is based on a real need to conserve water.
7. *Confidentiality*. A conservation program must be prepared to address the issue of protection of customer-supplied information deemed proprietary by the facility.

Nonresidential water use adds three other fundamental purposes besides domestic and landscaping: heat transfer, materials transfer, and use of water as an ingredient. The allocation of water consumption among these uses is site-specific, depending on such factors as facility type, age, size, locale, product or service, and climate. Examples of heat transfer uses include: single-pass cooling, cooling towers, evaporative coolers, and steam systems. Material transfer uses include rinsing or washing processes, transport, and pollution control or waste disposal.

It is difficult to establish a standard for determining whether a facility is water efficient without actually examining the operations of the facility. This is because even at facilities of the same type, the individual uses of water may differ. Climate is another major variable.

Site-specific studies or audits have provided information to quantify volumes of water for specific uses within facilities. The cost-effectiveness of water-efficiency measures can vary between facilities; measures that are cost-effective at one site may not be cost-effective or even applicable at another site.

Kobrick (1993) summarized nonresidential conservation programs for municipalities as:

- outreach and education
- financial incentives
- public recognition for companies that conserve

- research into emerging conservation technologies and to further understand their customers' water uses as well as document the results of previous conservation efforts
- ordinances and requirements.

Although mandatory requirements are often unpopular with many water customers, they are usually effective. The focus of ordinances should be on meeting local, State, or Federal requirements, or on preventing practices that clearly waste water and for which alternatives are available. They should be directed at uses of water that involve significant volumes. Some examples from Kobrick (1993) are:

- require separate meters on irrigation systems
- require the use of reclaimed municipal wastewater where available
- eliminate all uses of single-pass cooling water
- require separate meters on make-up and bleed-off water lines for cooling towers
- require a minimum number of cycles of concentration
- install ultra low flow plumbing fixtures
- require use of reclaimed water for some construction uses, such as dust control and compaction.

Anderson (1993) presents some water conservation examples from a large hotel in Austin, TX. They essentially include good maintenance and management practices and resulted in 30 percent savings for the hotel:

- Maximize cooling tower cycles of concentration (run 5 to 7 cycles).
- Use low-flow devices and fixtures.
- Use river water for irrigation.
- Use air-cooled refrigeration rather than once-through water cooling.
- Recycle ornamental river water.
- Computerize washing machines with minimum and maximum levels.
- Automatic shut-off valves and sensors on dishwashers.
- Use river water for cooling tower make-up water.

Bjorgum and Hernandez (1993) discuss some nonresidential case studies for water conservation in Denver, CO. Water audits conducted at several sites showed potential to save considerable water. Recommendations were based on a simple economic analysis comparing the installation costs to the potential benefit cost savings in energy, water, and sewer charges. Conservation measures with payback periods longer than 3 years were typically not recommended. The main categories were: domestic use, once-through cooling, washing and sanitation, and landscape

irrigation. Options include low flow fixtures and faucet aerators, identification of additional uses for the water, modify or operate the cooling equipment more efficiently or discourage the use completely. In washing and sanitation, options included: use of automatic on-off valves on the end of hoses used for washdown, sweeping with brooms where possible, promoting the efficient use of clean-in-place systems and educating employees on the concept of saving water. Irrigation suggestions included: using evapotranspiration (ET) rates and watering schedules, using automatic vs manual sprinkler systems, using sprinkler system lockouts during rain events, reducing sprinkling zone time, watering late at night or early in the morning, and converting turf to xeriscape-type landscaping.

Other industrial changes included: reusing ice flushing water in cooling towers, using countercurrent rinse systems in chemical rinse tanks, using closed-loop cooling systems for furnaces, using treated wastewater for fire-protection systems, changing aqueous degreaser to vapor degreaser,* adding sidestream filters to rinse tanks to increase cycles, using an automatic spray rinse system, and eliminating use of an open water storage reservoir. Primary savings in costs was for reduced pretreatment of wastewater. Another industry installed an automatic bucket washer to eliminate hand washing of buckets, an electric motion sensor on a basket washer, and implemented appropriate recycling of rinse water.

* Note that the Army is going the opposite way, i.e., from solvent and vapor degreasing to alkaline wash to address Toxic Reduction Inventory (TRI) goals.

8 Cooling and Heating

Cooling

Babcock et al. (1993) discuss the use of evaporative coolers in residences in the arid Southwest. They found that in peak summer months, about 20 percent of water use was for evaporative cooling with a single-case study of a high-efficiency unit using 213 gal/day.

Evaporative cooling is one of the most ancient and one of the most energy efficient methods of adiabatic cooling without use of a compressed refrigerant. It has long been regarded as environmentally friendly, as the process uses no ozone-depleting chemicals and makes about one-fourth the demand on the power grid during the peak cooling months of the year. In dry climates, evaporative cooling, even the relatively inefficient "swamp box" household coolers, can be used to cool relatively large unoccupied areas.

Evaporative coolers use water to increase the humidity of incoming air being drawn into a building and decrease its temperature. Most evaporative cooling equipment is used to cool air flow for space cooling. The air's ambient, or "dry bulb," temperature is lowered when the air absorbs water vapor. The saturation, or "wet bulb," temperature remains constant. After a short period of operation, recirculating water in an evaporative cooler assumes the wet bulb temperature of the entering air. This is theoretically the lowest temperature to which the entering air may be cooled. The measure of the approach of the leaving air dry bulb temperature to the entering air wet bulb temperature is the "saturation efficiency" of the cooler.

Direct evaporative cooling adds moisture to the air. In wet climates, or during the rainy season buildup in the desert southwest, this can make for a very uncomfortable and unacceptable dampness. Indirect evaporative cooling cools the indoor environment without adding humidity, but it is less effective, costs more, and if not used properly, can cause damage to refrigerant-driven cooling systems.

Evaporative coolers are used to cool air through the evaporation of water. Three types of evaporative cooler are: direct, combined, and indirect.

Direct evaporative coolers are comprised of several types: drip-type (known as "drip coolers"), slinger-type, and rotary-pad evaporative coolers. Drip-type coolers are the most common and are the most inexpensive and the simplest evaporative coolers — they yield the most comfort per dollar invested. However, they are prone to several problems associated with pad maintenance, occasional odors on start-up, cabinet corrosion, and lack of automatic controls. Drip cooler sizes vary with fan power and range from about 1/40 to 7.5 hp each or from a few hundred to 36,000 cfm washed air output. However, the designs vary remarkably little.

Slinger-type coolers are commonly found in offices, garages, work shops, and power plants. Slinger-type coolers can deliver between 3,000 and 40,000 cfm of washed air. These coolers tend to cost approximately twice the cost of drip coolers, but have shown better long-term performance and maintenance costs and fewer problems with odors on start-up. Slinger coolers are double priced compared with drip coolers (the prices range from $3,500 to $20,000). Recent studies showed that slinger-type coolers deliver about 30 percent less air volume per fan hp and about 40 percent less air volume per total hp. Additionally, excess spray striking the casing around and before the filters often causes external noise. However, slinger coolers are long-lived and extremely reliable. They require almost no maintenance, give very constant long-term performance without odor problems, and clean the air of almost all solids.

Rotary pad coolers were shown to substantially reduce maintenance and corrosion problems through better filtering. These coolers have shown important advantages in operating efficiency; in elimination of pumps, tubes, and orifices to wear or clog; and in the facts that pads are permanent, operation is almost silent, and there are no yearly replacements except for the dust filters. Major problems include high up front costs and comparatively large fan power requirements. However, these coolers seem the most trouble free and the first choice for many users.

Combined evaporative cooling systems are systems that combine direct evaporative cooling with refrigerative air-conditioning and heating. The climbing costs of power and equipment have stimulated a search for technologies to combine direct evaporative cooling with refrigerative air-conditioning and heating. For example, "add-on" evaporative cooling units are installed in homes or buildings already equipped with refrigerative cooling. The intent is to replace the refrigerative coolers with evaporative cooling when outdoor humidity is favorable. The system components operate alternately (not simultaneously) to reduce compressor use. Coolers are usually connected to joint ducts through automatic shutters or motorized dampers that open when the coolers start and admit washed air into the refrigerated system supply or return air plenums and then to the ducts. In the latter case, automatic shutters also close the return air grille connections, and the air-

conditioning blowers help push the washed air through the ducts (Bessamaire). "Add-on" evaporative cooling pays well if operated enough hours yearly. The minimum cost varies, first with equipment and operating costs, then with the price of power, the length of the cooling seasons, the weather during those seasons (and like variables), and user preferences. It should certainly be profitable in all traditional evaporative cooling states (Figure 4) and in border areas such as Kansas, Oklahoma, Arkansas, most of Texas, and parts of Illinois, Indiana, Nebraska, Iowa, Missouri, Tennessee, Pennsylvania, and even Georgia. Montana and the Dakotas are excluded only because of their short cooling seasons. Indirect evaporative cooling differs from the better known direct evaporative cooling because it cools air by the evaporation of water without contacting it. Indirect evaporative cooling involves two streams of air (primary and secondary) passing through the coolers simultaneously. The most substantial benefit obtained from indirect cooling is precooling air for refrigerative air cooling. It may treble the geographic area for direct evaporative cooling.

Geographic Range for Evaporative Cooling

The geographical range for evaporative cooling is usually based on the cooler's ability to create human comfort (Thompson and Chalfoun 1994). The range theoretically ends where regional summer humidity prevents success. The rule of thumb is that the greater the local ratio of dry-bulb hours equaling 80 °F or above to wet-bulb hours equaling 67 °F or above, the greater the number of hours of good cooling per invested dollar direct evaporative cooling can provide. Figure 4 shows general areas of the country where evaporative coolers may be useful.

The Economics of Evaporative Cooling

Most buildings have areas of windows to admit light in winter and air in summer. Unfortunately, they also admit both solar and atmospheric heat. Cooling is further complicated by liberating great internal heat. Each horsepower hour consumed liberates 2544 Btuh. Furnaces, electric apparatus, lights, office equipment, production machines, and all hot or wet processes add more, in some buildings up to 150 Btuh per sq ft.

Refrigeration removes humidity and vapors expensively, by condensing them at 1050 Btu/lb plus losses, or up to 175 watts/pint of water, other means are needed to remove vapor. Refrigeration cannot remove airborne dusts and lints at all: in fact, these may injure cooling units not protected by filters by clogging condensers, cooling coils, or controls.

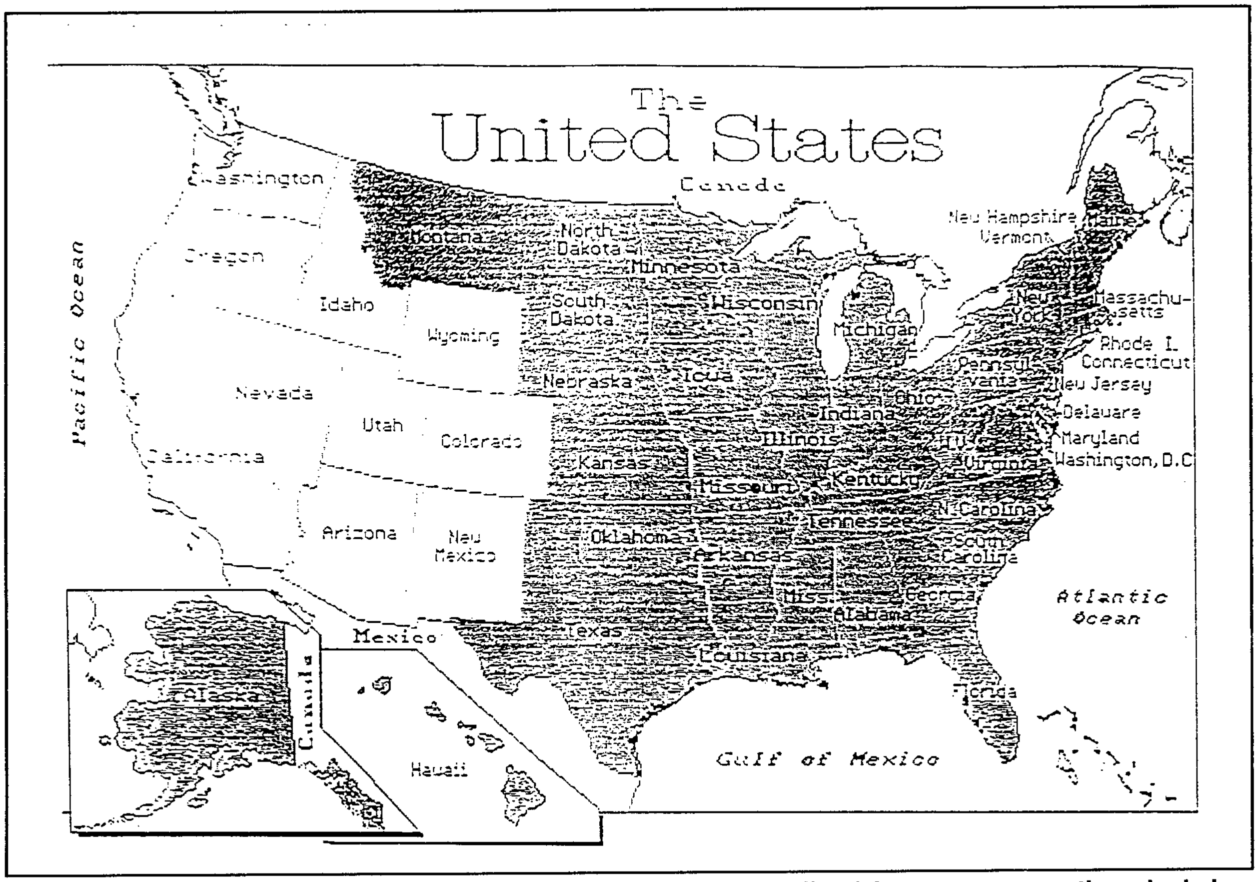

Figure 4. Map of the United States showing statistical need for cooling (clear area, evaporative; shaded area, refrigerative).

Beyond such heat load and pollution (dust and lint) control measures are equivalent investments in refrigerative cooling equipment, cooling towers, refrigerants, etc. Probably each dollar spent on the former type of investment saves one or more on the latter. Unfortunately, and unlike evaporative cooling, most such systems tend to be centralized, so, after basic equipment, they demand large expenditures for ducts, piping, remote air handlers, and wiring to distribute the cooling where needed.

In short, refrigerative cooling in most cases involves enormous investments.

Gordian Associates compared evaporative and refrigerative cooling costs. Their specific aim was to compare the relative cost-effectiveness of direct-evaporative, electric heat pump, and vapor-compression cooling for residences in the western United States (Figure 4). This study involved both direct and life-cycle yearly costs. The computer simulation found drip coolers cooling whole houses via ducts used about 70 percent less whole-season power than comparable refrigerative systems (Table 2). When gas furnaces were added, the cooler system saved 30 percent of total year-round heating-cooling costs over a mechanical system, and 40 percent over a heat pump (Peterson 1993).

Table 2. Evaporative cooler power savings.

City	Evaporative Cooler Power kWh	Evaporative Cooler Water gal.	High Eff. Refrig'n kWh	Saved by E.C. kWh (%)	Standard Refrig'n kWh	Saved by E.C. kWh (%)	Heat Pump kWh	Saved by E.C. kWh (%)
Burbank	1,305	5,086	4,175	69	4,995	74	4,287	70
Phoenix	2,500	21,639	9,681	74	10,255	76	8,818	72
El Paso	1,872	11,636	5,868	68	6,998	73	5,957	69
Denver	627	3,480	1,994	69	2,245	72	2,063	70
Spokane	415	2,168	1,380	70	1,554	73	1,430	71

Owning and Life-Cycle Costs for Evaporative Coolers

Accepted local design temperatures for the individual cities were used to compute house cooling and heating loads, and equipment and duct systems sized and installed.

Each hypothetical installation was priced by dealers quotation. For whole-year coverage, the evaporative cooler was first paired with a heating-only heat pump, then with a central electric furnace, and finally with a gas furnace. Table 3 summarizes the total installed costs averaged over the five cities.

These investments were converted to life-cycle costs by a perpetual replacement policy involving depreciation over estimated useful lives based on industry data, and first estimated maintenance costs (Table 4).

Table 4. Installed heating/cooling costs averaged over five sites.

Drip cooler and heating-only heat pump	$4,128
All-year heat pump	$3,947
High efficiency air-conditioner and electric furnace	$2,830
High efficiency air-conditioner and gas furnace	$2,776
Drip cooler and gas furnace	$2,440
Drip cooler and electric furnace	$2,365

Table 4. Replacement policy and estimated maintenance costs.

Item	Years	Upkeep ($)
All-year heat pump	9	150
Heating-only pump	9	150
Electric furnace	15	40
Gas furnace	16	60
Drip cooler	15	20
Mechanical air-conditioning	16	65

Table 5. Life-cycle owning and operating costs for cooling systems, averaged over five cities.

Life-Cycle Parameter	Cost
High efficiency air-conditioner	$648/year
Evaporative cooler	$316/year
Savings	$332/year

Table 6. Life cycle yearly comparisons.

Evaporative Cooler With:			High Efficiency A/C With:		
Heating Only Heat Pump	Electric Furnace	Gas Furnace	All Year Heat Pump	Electric Furnace	Gas Furnace
$990/year	$761/year	$645/year	$1,139/year	$1,052/year	$917/year

Maintenance and water costs were inflated 6 percent yearly and power rates were inflated 8 percent. Table 5 lists the yearly life-cycle owning and operating costs for the most pertinent cooling systems, average over the five cities.

Table 6 lists the corresponding life-cycle yearly average total costs involving the heating equipment, averaged over the cities.

So the evaporative cooler/gas furnace combination saved $494 or 43 percent life cycle total per year over the all-year heat pump, and $272, or 30 percent over the high efficiency refrigerative system with gas furnace.

Once-through Cooling

All uses of water for once-through (or "single-pass") cooling should be eliminated. Once-through cooling is the practice of running water continuously through an item requiring cooling, with the water going directly to a drain for disposal. Even a small flow rate can add up to a large volume and major expense for every item that is cooled by single-pass water.

Many sewerage regulations prohibit the discharge of uncontaminated once-through cooling water to sewer collection systems. Legal and cost issues make it imperative that once-through cooling be eliminated wherever possible.

Possible locations where once-through cooling water is found include:

- ice machines
- refrigeration systems
- air-conditioners
- process/ lab equipment
- air compressors
- vacuum pumps
- process tanks/baths.

Several actions can be taken to eliminate once-through cooling. Air-cooled models can replace many items of water-cooled equipment. For example, air-cooled ice machines can be installed in place of water-cooled models (see Chapter 11). Connect to a recirculating cooling water loop (such as a chilled water system, if present) instead of using once-through cooling.

Cooling Towers

Cooling towers are a much more water-efficient method of providing cooling compared to the once-through approach. Despite their water-efficiency, cooling towers are often the largest user of water in industrial plants, office buildings, hospitals, and other facilities with large air-conditioning or cooling loads. An understanding of the principles on which cooling towers operate and the wide array of water quality management techniques can help a cooling customer tap into the best savings potential.

The basic function of a cooling tower is to use evaporation to cool a recirculating stream of water (Figure 5). In a cooling tower, a circulating stream of warm water

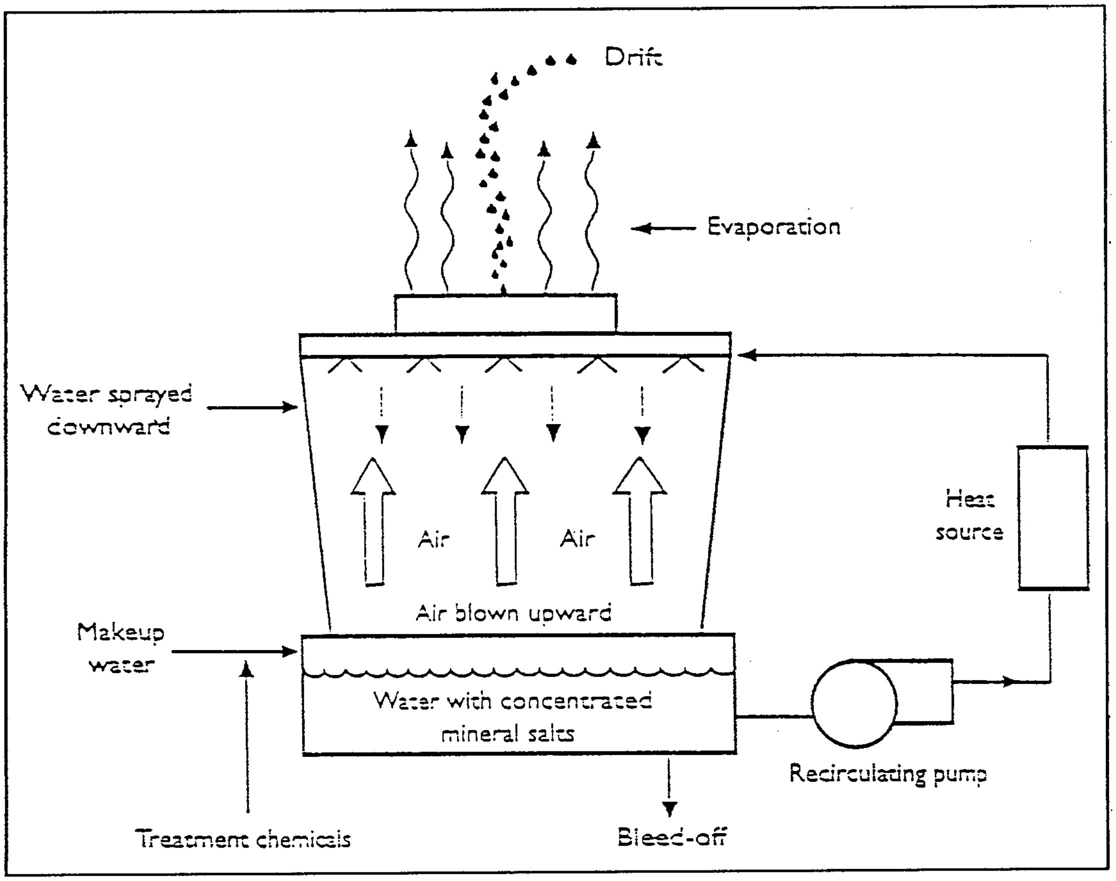

Figure 5. Cooling tower schematic.

contacts an air flow, causing evaporation of a portion of the water. The rate of evaporation from a typical cooling tower is approximately 1 percent of the rate of flow of the recirculating water passing through the tower for every 10 °F decrease in recirculating water temperature achieved by the tower. The loss of heat by evaporation (latent heat) cools the remaining water. A small amount of cooling also takes place when the remaining water transfers heat (sensible heat) to the air. The water cycles continuously through a cooling tower, to equipment that needs cooling. A heat exchange occurs: the equipment is cooled, and the water becomes warmer.

The cooling capability of a cooling tower or other cooling equipment is usually described in tons. This indicates the rate at which the cooling tower can reject heat. One ton of cooling is equal to 12,000 BTU per hour. Cooling towers at commercial, industrial, or institutional facilities typically range from as little as 50 tons to as much as 1,000 tons or more. Large facilities may be equipped with several large cooling towers.

The evaporation rate varies depending on the amount of cooling achieved, and to a much lesser extent, weather conditions. Water that evaporates from a cooling tower is pure vapor. As a rule of thumb, the rate of evaporative loss from a cooling tower

is equal to approximately 2.4 gpm per 100 tons of cooling. As an example, a cooling tower that provides 500 tons of cooling loses approximately 12 gpm (500 tons x 2.4 gpm/100 tons) to evaporation. If the cooling tower operates for a full day, this evaporative loss would total 17,280 gal/day. The dissolved solids in the water supply remain in the cooling system and concentrate in the recirculating water. As pure water continues to evaporate, the concentrations of the dissolved solids increase in the water circulating through the cooling tower system.

If dissolved solids are not limited to a reasonable level byN the cooling tower operator, their concentrations can reach levels that seriously damage the system. The potential water quality problems include scale, corrosion, and biological fouling. In most systems, dissolved solids are removed by releasing or "bleeding off," a portion of the recirculating water. The solids dissolved in the bleed-off water are carried out of the system. The flow of bleed-off water is usually controlled by timers, by conductivity meters, or (in some smaller systems) manual adjustment. Bleed-off usually is the only use of water in a cooling tower that can be reduced as a conservation measure.

Makeup water is the water added to the cooling tower to replace water lost to evaporation, drift, and bleed-off. The relationship between the concentration of dissolved solids in the cooling tower and in the make-up water is known as the "concentration ratio," or "cycles of concentration." The definition is expressed in the following equation:

$$\text{Concentration Ratio} = \frac{\text{Concentration of Cooling Tower Water}}{\text{Concentration of Make-up Water}} \quad \text{[Eq 1]}$$

The relationship between quantities of makeup water and bleed-off can be expressed in terms of the concentration ratio, or the cycles of concentration. The concentration ration (CR) can be thought of as an indicator of the number of times water is used in the cooling tower before it is discharged as bleed-off. Assuming that nothing is being removed from the system except evaporation, bleed-off, and drift, the concentration ratio is equal to the quantity of makeup water (M) divided by the sum of bleed-off (B) and drift.

Under normal conditions, drift should be minimal, and can in most cases be considered a small part of the bleed-off. This enables the concentration ratio to be expressed more simply as the ratio between makeup water volume and bleed-off volume. This can be calculated if the facility meters its makeup and bleed-off water.

At many facilities, makeup and bleed-off water are not metered. However, there is another method of calculating the concentration ratio where metering is not

available. The second method is based on the concentration of total dissolved solids (TDS) or an individual constituent. This calculation is based on a mass balance between dissolved solids entering the system in makeup water and dissolved solids leaving the system in bleed-off water, which can be expressed as:

$$CR = \frac{M}{B} = \frac{CB}{CM} \qquad \text{[Eq 2]}$$

The concentration ratio can be calculated very easily, based on the ratio of the concentration of TDS in bleed-off water (or circulating water) to the concentration of TDS in the makeup water. TDS is usually measured with conductivity meters, but inexpensive hardness test kits may also be used. A hand held conductivity meter may be purchased for as little as $40, while hardness test kits often cost less than $20.

Decreasing the amount of bleed-off, with evaporation remaining constant, will result in a higher concentration ratio. Figure 6 illustrates the relationship between concentration ratio and total water consumption. As the concentration ratio increases, the total water consumption decreases. Concentration ratios vary depending on incoming dissolved solids in a water supply, but values ranging from 6 to 12 are usually achievable. Towers at Army installations are usually below this range.

Significant reductions in water consumption can be made by increasing the concentration ratio if you have been previously operating at a concentration ratio of about 6 or less. If the concentration ratio is 10 or greater, only a small additional amount of water can be conserved. The reason is that cooling towers operated at these high concentration ratios lose 90 percent or more of the water consumed to evaporation, which cannot be reduced. Figure 7 shows a chart to determine the percentage of water savings you can achieve from increasing the concentration ratios at which a cooling tower operates.

In evaluating a cooling tower system, it must be noted that the concentration ratio is not the sole criterion for appropriate performance. Source waters with higher TDS concentrations will result in higher concentrations in the recirculating water in a cooling tower system. Therefore, proper management of cooling water includes examination of the specific constituents of the water and their potential for causing scaling and other problems.

Left uncontrolled, the quality of the water circulating through a cooling tower system will deteriorate, influenced by the quality of the makeup water and the quality of the air passing through the tower.

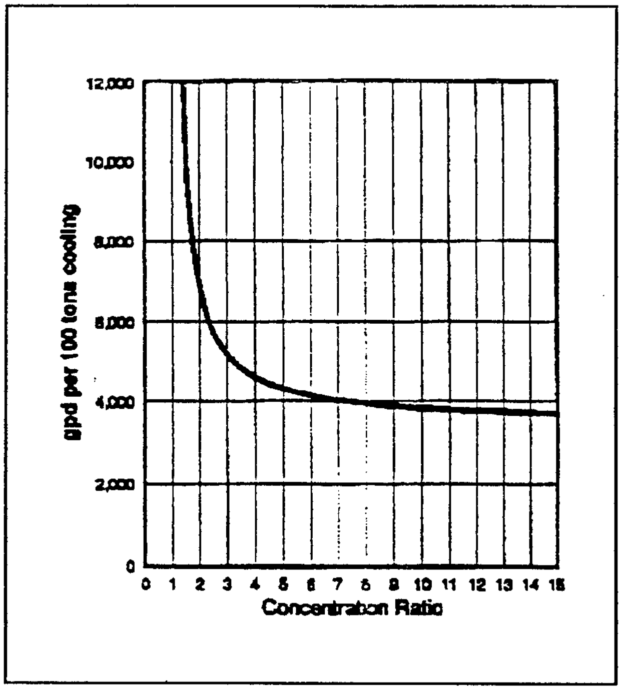

Figure 6. Relationship between concentration ratio and cooling tower consumption.

Concentration ratio before	Concentration ration after											
	2	3	4	5	6	7	8	9	10	12	15	20
1.5	33%	50%	56%	58%	60%	61%	62%	63%	63%	64%	64%	65%
2		25%	33%	38%	40%	42%	43%	44%	44%	45%	46%	47%
3			11%	17%	20%	22%	24%	25%	26%	27%	29%	30%
4				6%	10%	13%	14%	18%	17%	18%	20%	21%
5					4%	7%	9%	10%	11%	13%	14%	16%
6						3%	5%	6%	7%	9%	11%	12%
7							2%	4%	5%	6%	8%	10%
8								2%	3%	5%	6%	8%
9									1%	3%	5%	6%
10										2%	4%	5%
12											2%	4%
15												2%

Figure 7. Percentage of water savings achievable by increasing cooling tower concentration ratios.

The thermal efficiency, proper operation, and longevity of the cooling system directly depend on the quality of the recirculating water. The principal concerns of water quality are scale, corrosion, and biological fouling (biofouling). These factors are why bleed-off from cooling towers is necessary, and why a large majority of facilities chemically treat the recirculating water to inhibit or control these problems.

Army readers should consult with USACPW, Alexandria, VA, or one or more qualified, reputable water treatment chemical suppliers or equipment vendors (whose claims are reasonable and verifiable) offering their services in your area. Marine Corps readers are encouraged to contact NAVFAC or NFESC (Naval Facilities Engineering Service Center) for similar service. There have been a number of problems where unsuspecting customers are not being given proper service or are being sold unnecessary or useless treatment options, equipment, and chemicals. The facility manager should be aware that many products are marketed with exaggerated or unfounded claims about their effectiveness or safety. When you have found a reputable vendor, work with them. Ask for explanations of chemicals and purposes and actions of chemicals. Indicate that water conservation is a priority and ask about alternatives. Establish a performance-based specification including requests for water and chemical consumption and costs.

Water Conservation Opportunities

Water conservation for a cooling tower results from reduced use of water for bleed-off. In addition to these savings, wastewater service charges can also be decreased because of the lesser volume of bleed-off discharged to the sewer. Another potential savings, which is sometimes overlooked, is decreased chemical consumption. Sometimes, sewage fees are based on water consumed rather than actual volume discharged. Where evaporation is a major factor, the installation should pursue an adjustment of the bill.

Methods used to prevent scale formation include chemical treatment with scale inhibitors (such as organophosphates), and bleed-off to reduce the mineral concentrations. Corrosion and biofouling can be controlled by the use of corrosion inhibitors and biocides, respectively. These chemicals are added into the recirculating water by automatic feeders, which may be controlled based on the conductivity of the water, the volume of make-up water added to the system, or by timers. Most facilities contract with a commercial water treatment firm to supply the chemicals and manage their use.

In addition to the water quality problems described above, many types of foreign matter, such as dust and oil, can become entrained in a cooling water system. The primary source of foreign matter is airborne pollution. These contaminant particles increase the turbidity of the cooling water, and can clog the water distribution systems, obstruct passages in the fill, and settle out in the low velocity areas, making frequent cleaning necessary.

Monitoring

Proper maintenance of the cooling tower is essential, not just for water efficiency, but also to protect the tower and prolong its life. The performance of the cooling tower system should be monitored and the data recorded and reviewed, to ensure efficient cooling performance and for water conservation.

Prepare an inventory of each cooling tower, its cooling capacity, and the equipment or processes that it serves. Meter and record the amount of make-up water added to each tower, and the amount of bleed-off water discharged from each tower.

Decrease Bleed-Off

Reduce the amount of bleed-off discharged from the system to the minimum level consistent with good operating practice. Bleed-off is the release of some of the circulating water to remove suspended and dissolve solids. Reducing the amount of bleed-off is usually accomplished by treating the cooling water by physical or chemical means to enable more recirculation through the system.

Conductivity Control

Because conductivity is an indicator of the concentration of dissolved solids in the system, a conductivity meter can be incorporated in a control unit to regulate the discharge of bleed-off from the cooling tower. This common practice is far superior to the use of manual bleed-off control. Using a conductivity controller will result in bleed-off being discharged only when the concentration of solids in the system exceeds a pre-set level.

Improved Operation of Conventional Treatment

Much can be done by conventional chemical treatment to enhance the water efficiency of cooling tower operations. A large part of this effort involves monitoring the system's performance with conductivity controllers and flow meters.

Install flow meters on the makeup and bleed-off water lines to closely monitor the operation of the cooling tower. This will enable the operator to verify that the tower is operating within specified limits. Meters used should be capable of totalizing the flow. Meters that also display instantaneous flow are even more useful. Remember that the meters are only useful if they are read and recorded on a regular basis.

Maintain the tower to the manufacturer's specifications. This includes checking all valves for proper operation. The float valves in the tower basin are notorious for getting stuck.

Improve the method you use to release bleed-off. Most cooling towers are bled off automatically when the conductivity of the water reaches a preset maximum level indicating high TDS. This is usually done by the batch method, discharging large quantities of water for a preset period of time or until the conductivity reaches a preset low value. This method can allow wide fluctuations in conductivity, which will waste water. It is better to operate the bleed-off on a more continuous basis, maintaining the conductivity of the tower water closer to the limits. Set the bleed-off timer for a shorter duration, or set the low-end conductivity higher (not much less than the bleed-off start level). In addition to conserving water, maintaining a uniform water quality reduces the chemical requirements.

Set a policy that water conservation is important when selecting your cooling tower water treatment vendor. Require vendors to submit projections of quantities and costs of treatment chemicals and volumes of bleed-off water. This will enable you to select a vendor based on the true cost of operating the tower.

Advantages

- low initial cost
- low operating cost
- low maintenance requirements.

Disadvantage

- limited cycles of concentration.

Sidestream Filtration

Consider installing a sidestream filtration system. These are particularly effective where the turbidity is high, where airborne contaminants such as dust or oils are

common, or where the cooling water passages are small and susceptible to clogging. Filtration systems remove particles or suspended solids in the recirculating water enabling the system to operate more efficiently with less maintenance.

Typical cooling tower filtration systems continuously draw water from the basin, filter out the sediment, and return the filtered water to the tower. The most common types of filters are rapid sand filters and high efficiency cartridge filters.

Although filtration can be accomplished at any point, the most efficient way is to draw water from the center of the basin, pass it through the filter, and return the filtered water through spray nozzles or perforated piping arranged so that any sediment is swept to the filtration system collection point. Filtration rates typically range from approximately 5 percent of the total circulation rate to as much as 20 percent for systems where particulates are a problem. The advantages of a filtration system are reduced potential for scale and fouling, and longer periods between shutdowns.

Advantages

- reduced possibility for fouling
- higher operating efficiency
- reduced maintenance.

Disadvantages

- moderately high initial capital investment
- limited effectiveness for dissolved solids removal
- additional energy costs for pumping.

Sulfuric Acid Treatment

The Army (USACPW) does not recommend the use of sulfuric or any other acid for scale control in cooling tower systems. Proper use of chemical treatment will achieve the desired goals without the health considerations.

Ozonation

One supplement to chemical treatment of cooling water is ozonation. Ozone, one of the most powerful oxidizing agents available, has been used for many years as a

disinfecting agent for water supplies. It is an effective biocide but chemical treatment is still necessary for scale and corrosion control.

Ozone controls viruses and bacteria by rupturing the cell membrane and killing the microbes in the water. Its effectiveness in controlling scale, and possibly removing existing scale, is still being evaluated.

A typical ozonation unit consists of an air compressor, an ozone generator, a diffuser or contactor, and a control system. Ozone is an allotropic form of oxygen (O_3), which has a half-life of less than 1 hour. Because of this short half-life, it must be generated on-site. Ozone is produced by passing cool, dry air (or pure oxygen gas) through a high voltage field between two electrodes. Typically, the ozone is then applied by an in-line contactor that mixes the ozone gas with the cooling water. The ozone gas will degenerate to molecular oxygen very quickly. The rate of degradation increases rapidly at temperatures above 90 °F. Careful consideration should be given before attempting to apply ozone to systems where the water temperature exceeds 90 °F.

The drawbacks to using ozone are the complexity of the ozone generator system; the capital cost of the system; and the possible health hazards associated with its use. Many manufacturers offer leasing agreements that include maintenance and allow the user to test the system without a large capital investment. Ozone in large quantities is toxic. Safety precautions must be observed to protect plant workers from excessive exposure.

The success and potential water savings of ozone depend on the existing system and the application. Ozone is a powerful oxidizer and has been reported to attack system materials of organic origin (wood, certain types of rubber) when overapplied.

Advantage

- higher cycles of concentration possible.

Disadvantages

- high capital investment
- complex system, possibly requiring outside contractor for maintenance
- additional energy costs
- possible health hazard
- limited effectiveness at water temperatures above 90 °F.

Alternative Sources of Makeup Water

The use of reclaimed or recycled water in cooling towers conserves water because no additional potable water is consumed. In many instances, water used for another process within a plant can be used for cooling water makeup water with little or no pretreatment. Some of the options available may include reject water from reverse osmosis systems, and water from once-through cooling systems, or from other plant processes provided that any chemicals used are compatible with those used in the cooling tower system. Reverse osmosis system reject water should be chemically evaluated as it will hasten the buildup of TDS and the requirement for blowdown if TDS levels are high.

Advantages

- low-cost water source
- maximum water conservation, including elimination of fresh water loss to evaporation.

Disadvantages

- possible requirements for pretreatment
- additional chemical cost for pretreatment
- increased possibility for fouling if poor quality water is used
- possible additional energy costs for pumping.

Anderson (1993) discusses water consumption at the University of Texas, Austin. The largest water users are classroom buildings (27 percent) and chill stations/ cooling towers (26 percent). Lab water that would normally go down drains is collected and recycled to the cooling towers as makeup water. Over 50 million gal a year are recovered for the five, 10,000 ton cooling towers.

Boilers and Steam Systems

Boilers and other sources of steam are commonly used in large heating systems or at facilities where large amounts of process heating are used. Water consumption rates of boiler systems vary depending on the size of the system, the amount of steam used, and the amount of condensate return. Water is added to a boiler system to make-up for the water losses, and to replace water lost when the boiler is blown down to expel any solids that may have built up. The water in the boiler is treated with various chemicals to inhibit corrosion and scale formation in the steam

distribution system. Conserving water in steam systems will reduce water, energy, and chemical purchase costs through any of several conservation measures:

1. Recover steam condensate and return it for reuse as system make-up water. Water use, energy, and chemical consumption will be reduced by installing a condensate return system. Energy is conserved because the returned condensate is still warm and requires less heating than incoming tap water. Condensate return may reduce operating costs for a steam system by up to 50 to 70 percent.
2. Steam traps and lines should be checked for leaks and repaired promptly. Steam traps are an important component of a steam system's efficiency. Old or worn traps allow steam to escape without providing benefit to the system. This wastes both water and energy. Most steam traps can be easily repaired by plant operations personnel with replacement kits available from the manufacturer.
3. Steam and condensate piping should be insulated to conserve heat energy and reduce steam requirements.
4. Limit the amount of blowdown to match water quality requirements. Check continuous blowdown systems to be sure that an excessive amount of water is not being discharged from the system.
5. Blowdown should be discharged via an expansion tank allowing it to condense and cool. Avoid the use of cold water mixing valves for blowdown cooling; if your facility does have such mixing valves, check them to be sure that the water does not flow continuously and consider replacing them with an expansion tank.
8. Use of an automatic control as a possible retrofit may be investigated to shut off the unit during unoccupied night or weekend hours.

9 Hospitals

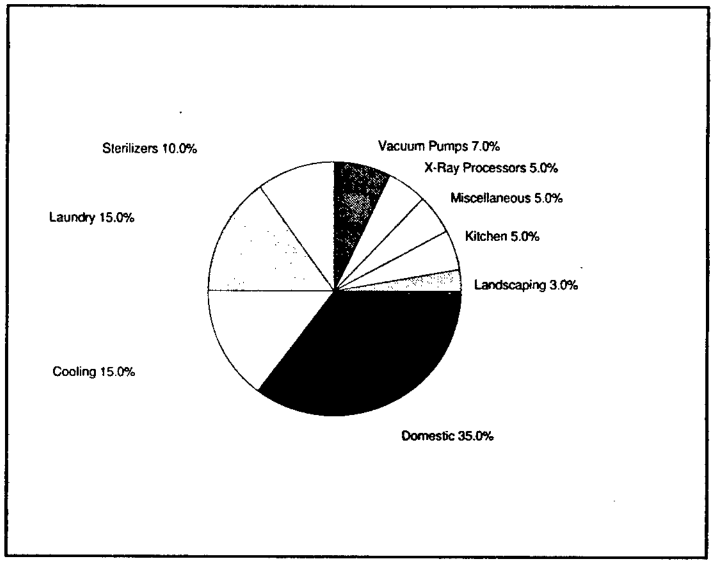

Figure 8. Typical water use in hospitals.

Wilson (1993) discusses water conservation for hospitals and health care facilities. Hospitals and health care facilities use large volumes of water, which means there are excellent opportunities for savings. Review of water data consumption by western U.S. water agencies shows substantial variation between similarly sized facilities on a "per patient per day" basis. Facilities with similar patient occupancies vary primarily due to the specific mixes of services they offer and operating procedures they use. Some of these variables include the presence or absence of in-house laundry facilities, landscaping, and variations in heating, cooling, and other equipment used in the physical plant. Even though overall water use cannot be accurately compared from one facility to another based on the number of patients, trends exist between different facilities based on specific uses. Figure 8 shows these trends as percentages of total water use. Typical uses of water and viable opportunities for water conservation are described below.

Domestic

The largest user of water in hospitals and health care facilities is in restrooms. (Chapter 4 gives additional information on water conservation options in this area.) Regular maintenance is especially important in this area. A scheduled program of leak detection and repair can provide considerable savings in water and energy costs for a small increase in maintenance effort, particularly at larger and older facilities.

You may also want to consider installing automatic sensor controls for toilets and urinals. These systems use a beam of infrared light to control flushing. In addition, because there is no need for the user to contact an activating device, these devices may ease use by the handicapped and help prevent the spread of disease. Another option is the use of pressure reducing valves to reduce pressures to 60 psi. To protect plumbing against damage, the Uniform Plumbing Code requires a pressure reducing valve when main pressure is greater than 80 psi. Plumbing systems typically are designed to perform acceptably at 60 psi.

Laundry

When laundry facilities are on site, the water demand is often second only to domestic demand in hospitals. Water may be conserved through a variety of mechanisms (detailed in Chapter 12) by optimizing existing equipment flows, installing water conserving washers, including continuous-batch type units, or installing water recycling systems. Plumbing codes and health care regulatory agencies often prohibit the use of washer recycle systems in health care facilities due to the possibility of contamination between the different wash loads. Local regulatory agencies should be consulted before installing any type of recycling system in a health care facility.

Cooling and Heating

Hospitals and health care facilities often have extensive heating and cooling systems. These systems often involve the use of cooling towers, chilled water systems, boiler systems, and evaporative coolers. Cooling towers often represent one of the single largest opportunities for water conservation within a hospital. (Chapter 8 gives more information on the topic of cooling and heating.)

Many hospitals have equipment that is cooled by a single-pass flow of water. After passing through and cooling the equipment, the water is discarded. Equipment that might be cooled by single-pass water includes: ice-making machines, air-conditioners, air compressors, and vacuum pumps. The discharge of uncontaminated water to the sanitary sewer is often prohibited to reduce unnecessary hydraulic loading on the wastewater treatment facilities. Much more efficient water use would involve connecting the equipment to a cooling tower system or using the single-pass effluent from some other use in the plant's process or optimally replacing the equipment with air-cooled units.

Sterilizers

Sterilizers are also the site of significant use of water in hospital and health care facilities. This is due to the relatively large number of sterilizer units found at most hospitals, the different ways in which they use water, the lack of flow controls on many older units, and the need to have units available 24 hours/day.

Three types of sterilizers are commonly used in hospitals: ethylene oxide (EtO) sterilizers, steam sterilizers, and washer/sterilizers. EtO sterilizers use water to draw the necessary vacuum, to assist in discharging the ethylene oxide gas, and require steam to humidify the load and vaporize the EtO gas at a heat exchanger. Total water use is less for the EtO units than for the steam sterilizers, which use steam to sterilize the load, and water to create vacuum and, in some instances, to cool discharged steam and/or hot water. Washer/sterilizers use water baths with ultrasonic waves to loosen the debris left on instruments. After the units are thoroughly cleaned, high pressure water sprays are used to rinse the instruments. Whenever most sterilizers are on, steam and water are flowing. This is intended to maintain steam quality and then cool the steam discharged to the sewer. Unless the machine is equipped with an optional feature that automatically shuts down all utilities to the unit when not in use (or unless the machine has been retrofitted to do this), steam and water will continue to flow at all times.

The required flow rate of water and steam condensate being discharged from the sterilizers should be confirmed with the manufacturer or service contractor. Utilities should be shut off whenever the units are not in use. The steam supply should be of very high quality (contain minimum scale or corrosion inhibitors) to maximize the water efficiency of the sterilizer. Finally, when a new sterilizer is purchased, the automatic utilities shutdown feature should be selected. Other methods of reducing the water consumption through steam sterilizers involves using an expansion tank to cool the steam condensate from the unit before discharge to the sewer. Note that the steam condensate from a sterilizer is not appropriate for reuse in the boiler system. The steam condensate discharge from a sterilizer may contain contaminants from the items being sterilized. Introducing contaminants back into the boiler system will allow contamination of the entire system and poses a health hazard. Another method of conserving water in steam sterilizers is to recycle the water used for cooling and drawing a vacuum on the unit. Since this water does not enter the sterilizer, there is no possibility of contamination.

Water-Ring Vacuum Pumps

Water-ring vacuum pumps are often scattered around hospitals, on roofs, and in basements. The flow of water flow is used for both sealing and for cooling the unit. The flow rate required by each unit should be verified with the manufacturer. Control valves should be used to limit the flow of water to only those times when the unit is in operation. Water-ring units can also be replaced by oil-ring vacuum pumps. Another opportunity for water conservation is to install flow restrictors on water-ring vacuum pumps.

X-Ray Processing

X-ray film processors are automated units used for developing X-rays. Water is used to rinse chemicals used during the developing process. Often the flow rate is set two or more times greater than that required by the manufacturer. In addition, the units should be equipped with controls to allow water flow only when product is being processed and to shut off when the machine is off.

Almost all hospitals and many other health care facilities take and process X-rays. Processing is done with automated equipment. Water-conserving technologies related to X-ray processing have been researched and developed in part to meet regulatory requirements pertaining to silver in wastewater discharges. Water can be saved by modification in operation and equipment, and by using reclamation and recovery systems. X-ray processing involves a series of complex chemical transformations. In general, these processes must develop, stop, fix, harden, wash (rinse), bleach, and dry the film. Some of these steps are repeated, omitted, or combined in the various specific types of processing that are performed. Automatic processing equipment contains tanks and dryers that operate in series to provide the necessary process steps. A transport system moves the film from one tank to the next. Most modern automatic processing equipment has solenoid control valves that open to feed water for wash purposes only when film is being processed. This is a water-saving feature, but these valves must be properly maintained to perform as designed. Retrofit valve kits are available for some models. Regulating valves are also available to limit the flow rate of the wash water to a set quantity.

The first step for water conservation in x-ray processing operations is to ensure that the facilities and equipment in place are operated as water-efficiently as possible. At many hospitals, the flow rates through x-ray film processors are higher than necessary. In many cases, a flow rate of 2 gpm or less is sufficient for effective processing, but the actual rates used are 3 to 4 gpm or even higher. This can be

corrected by simply adjusting a valve to reduce the flow rate to the minimum rate that still provides for good processing results. One approach to this would be to install an inexpensive flow rate meter on the water line feeding each processor. This would enable staff to adjust flows and ensure that the appropriate rate of rinse water is being received by the processor. Silver may be recovered from the solution being discharged to drain. This is desirable to minimize the amount of silver discharged to the sanitary sewer, and to recover a valuable metal. A silver recovery unit is an optional feature external to the film processor. Recovery units typically operate in one of two ways: the electrolytic method, in which the silver is plated out on electrodes, or the ion-exchange method, in which iron is exchanged for silver in the waste stream. Recovery units must periodically be regenerated or replaced.

Kitchens and Cafeterias

Many hospitals have substantial food service responsibilities and therefore maintain kitchens and cafeterias for patients, guests, and staff. Chapter 10 gives options for water conservation for those areas. Water in these areas is used primarily in dishwashing operations, garbage disposers, and ice makers.

Turf and Landscape Watering

There are a number of ways to conserve water used for landscape irrigation. Chapter 15 provides additional information on topics such as irrigation, the concept of xeriscape, site maintenance, etc.

Code Requirements and Regulatory Agencies

Many States have separate agencies that regulate all construction or modifications for hospitals or health care facilities. Whenever a water conservation project is considered, all regulatory agencies and local code requirements should be met.

Miscellaneous

Miscellaneous uses include those for laboratories, softener regeneration, and cleaning purposes. Most uses of water in hospital laboratories are relatively small, and generally have limited potential for water conservation. These include mixing solutions and washing glassware and other equipment. Some wasteful uses of water

do occasionally occur. The use of a running stream of water through an aspirator to create vacuum is wasteful. Some laboratory instruments, such as some automated analyzers, generate heat and require cooling. Sometimes a stream of single-pass cooling water is used for this purpose. This should be avoided. If available, chilled water from the hospital's recirculating system should be used in place of single-pass cooling, and mechanical vacuum pumps could be used in place of water aspirators.

Most hospitals soften water to be used in their laundry, boilers and hot water systems, and some also soften water for sterilizers, kitchens, and other uses. The most common softening system is the ion exchange method known as zeolite softening. In zeolite softening, the water passes through a resin that takes up calcium and magnesium ions (hardness) and replaces them with sodium ions. A device may be used to monitor treated water quality or volume, a timer may be used, or facility personnel many manually initiate regeneration. Water is consumed during the regeneration cycle to flush the resin and to refill the brine tank. Brine solution resupplies the resin with sodium ions. Water will be used most efficiently for softening when softening treatment is provided only to those flows requiring it, when regeneration is initiated by water quality monitoring, and when flow rates and cycle times during regeneration are properly set.

10 Kitchens, Mess Halls, Restaurants, and Cafeterias

Water in these areas is used primarily in dishwashing operations, garbage disposers, and ice makers. Water is also used in various other steps such as food preparation, sanitation, and clean-up. Occasionally, ice cream or frozen yogurt machines (which may consume water) are also present. Commercial spray-type dishwashers are designed to clean dishes, flatware, and glassware by washing with detergent and hot water, and to sanitize the dishes by application of hot water or chemical solutions. There are several types of commercial dishwashers to clean different volumes of dishes and utensils. In a stationary rack machine, dishes are loaded into a rack that fits inside the machine. Complete wash and rinse cycles average from 1 to 3 minutes. In a conveyor-type machine, dishes are loaded onto a conveyor belt that travels through the machine at speeds from 5 to 8 ft/minute. The final dishwashing rinse is accomplished with either hot fresh water or with a chemical sanitizing agent mixed with water.

Minimum wash and rinse requirements for dishwashers are established by the National Sanitation Foundation (NSF). Typical water use requirements are 4.5 to 6.0 gal/cycle of wash and rinse for stationary rack machines using water for the final rinse and approximately 2.5 to 3.0 gal/cycle for similar machines using a chemical sanitizing agent. Commercial dishwashing machines typically reuse the final rinse water to wash the succeeding rack of dishes. The way in which a dishwasher is operated affects the efficiency of its use of water. Higher efficiency can be achieved by operating the equipment properly, washing full loads, and using water flow rates no greater than those specified by the manufacturer. Final rinse water is often reused in the wash cycle or elsewhere for low-grade uses such as prewashes, garbage disposers, or food scrappers. This can offer energy savings as well. Pressure and flow regulators are available to maintain the desired flow during periods of high water supply pressure. Some conveyor-type machines are equipped with an "electric-eye" that detects the presence of dishes moving along the conveyor, and actuates the flow of water accordingly.

Commercial garbage disposers grind solid wastes into small particles so that they can be disposed of and conveyed through a sewer system. The ground garbage is passed into a mixing chamber where it is mixed with water for disposal. In larger

systems, the garbage disposal is often preceded by a scrapping and preflushing system that uses water to carry scraps to the disposer. For some larger systems, a conveyor can be used instead of a scrapper to transport waste to the disposal. Water conservation opportunities for garbage disposers include reducing preset run times, installing flow regulators to limit the amount of water discharged through the unit, eliminating the garbage disposer, or replacing the disposer with a garbage strainer. A strainer-type waste collector passes a recirculating stream of water over food held in a basket, reducing the waste volume by as much as 40 percent by washing soluble materials and small particles to the sewer. The holding basket is periodically emptied. The water consumption rate for these units is approximately 2 gpm, considerably less than the 5 to 8 gpm requirement of garbage disposers. In fact, some restaurants do not use garbage disposers because they frequently require repair or replacement. By eliminating garbage disposers, you may also reduce maintenance costs.

If removal of the disposer is not possible, control the water flowing to it by a solenoid valve that shuts off the water when the disposer motor shuts off. Many disposers have two water supply lines, one to the bowl and one to the grinding chamber. Be sure to check both.

Contact the manufacturer of the disposer to determine the minimum possible flow rate through the disposer and adjust accordingly.

Some garbage disposers' controls are set to operate for a preset period every time the disposer is turned on. Reduce the run time to reduce water consumption.

Miscellaneous conservation techniques are:

- Repair leaks in steam, hot water, and cold water lines.
- Do not thaw frozen foods with a running stream of water; plan ahead and thaw in a refrigerator. If water-thawing is necessary, a running stream of water should be used for health reasons, but use a slow flow.

As with ice makers, soft-serve ice cream and frozen yogurt machines are available with two different types of condensers: water-cooled, and air-cooled. Most water-cooled units use a single pass of cooling water. One option, as with ice makers, is to replace the unit with an air-cooled unit that does not require any water for condenser cooling. Alternatively, the unit could be retrofitted to be cooled by the kitchen or installation's chilled water system, if available, or by remote air-cooled condensers.

Plate cleaning troughs are often used to carry food scraps and other waste to a garbage disposer. Two different types are available: scrapping troughs, and on larger systems, conveyors. The scraping system uses a flow of water in a trough to carry food scraps to the disposal. The conveyor system uses a conveyor belt to carry the waste to the disposal. Typical scrapping troughs use between 3 and 5 gpm of fresh water. They can be controlled automatically to operate whenever the dishwasher is in use, or with a manually operated push-button. Conveyor-type systems do not use any water; all water consumption associated with these units is by the associated garbage disposer. Measures to reduce water use associated with plate cleaning troughs include installation of pressure regulators to eliminate excess water usage, use of automatic timers and shut-off valves to limit operating time. The most significant method is to eliminate the use of the scrapper since it is not necessary to dispose food waste to the sewer system.

Be sure that the flow of water through the dishwasher stops when the flow of items being washed stops. Although the flow of water in many dishwashers shuts off when the conveyor stops, many times the conveyor continues to move when no dishes are present, and water flows needlessly. Equip conveyor-type machines with an "electric-eye" to detect the presence of dishes moving along the conveyor, and to control the flow of water accordingly.

Check your dishwasher to be sure that it is not using an excessive amount of water. Experiment with a modest reduction (about 10 percent) in the flow rate of water to your dishwasher to see if any problems result. If no problems occur, continue to operate at the reduced flow rate. Consult with the equipment manufacturer or your service contractor before making major changes.

Many dishwashing workstations have a prewash spray fixture to rinse plates before washing. Flow rates discharged from these units should be reduced to the minimum necessary. Also, spray rinse fixtures are often subject to hard use and frequently develop leaks. Leaking fixtures should be replaced.

11 Ice Makers/Machines

Ice-making equipment can be divided into two different groups: ice cube and ice flake machines. Both of these types of ice have the same ice production cycles, the freeze and the harvest cycles. The freeze cycle is when the ice is produced on the evaporator, while the harvest cycle is when the ice is removed from the evaporator. Flake ice and cube ice can also be further divided into clear ice production and cloudy/white ice production. The color of the ice makes a big difference when it comes to water and energy consumption. The methods used to produce ice cubes and flaked ice are different. Ice cube making is usually a batch process, while the flake ice making is usually a continuous process.

The goal of ice cube machines usually is to produce clear ice cubes. Cloudy ice cubes can be caused by minerals or other substances frozen in the ice. Most ice cube machines are designed to wash the frozen surface of the cube as it forms. The dissolved salts in the water depress the freezing point of water. Therefore, pure water will freeze first, leaving the salts in the runoff water. The frozen water in cube ice, therefore, typically is purer than the source water. This is called the batch process, which is required for the production of clear ice.

Cube ice machines allow a variety of different shapes and sizes of cubes. Flat plate evaporators allow the water to freeze with a variable cube thickness. However, the thinner the ice cubes, the more thermally efficient the process will be. At the end of the freeze cycle, the flat plate is heated to release the chunk of ice over a hot wire grid to cut the individual cubes. The flat plate could also be adapted with the grid in place so the water is actually frozen in cube form. This would allow for the removal of the hot wire that cuts the cubes. The cubes could also be formed with multiple cell molds in a variety of different shapes. This makes these machines very versatile, but the ice production is still made in the batch process, which wastes water and energy.

The part of the process that wastes water is the clear ice production with the batch process and the bleed-off water. If the color of the cubes does not matter, the cubes would not need to run-off the contaminants/minerals that cause the ice to appear cloudy. Unfortunately the use of ice cubes usually requires them to be clear because they have a better appearance. In some instances, cube ice making equipment uses

as much as 20 to 25 gal of water to produce 100 lb of clear ice cubes. Because 100 lb of ice is equal to approximately 12 gal of water, it is evident that approximately 13 of the 25 gal used to produce the cubes is not frozen, but is drained from the ice cube making machine.

The cube machines come in both water-cooled process or an air-cooled process. The air-cooled process is the simplest and the best choice unless the HVAC system of the building cannot handle the extra load of the heat exhausted from the ice making system. If this is the case, there are two options: a remote air cooling system or a water-cooled system. A remote air-cooling unit could be located adjacent to the ice machine, which would allow the machine to reap the benefits of the air-cooled process. The hot air could be exhausted outside, thereby not interfering with the existing HVAC system in the building. If this is infeasible, the best option is a water-cooled unit. Water-cooled ice makers generally use slightly less electricity than air-cooled machines. Most water-cooled ice makers do not recirculate the condenser cooling water. For typical ice makers, ranging in capacity from 400 to 1,200 lb of ice per day, approximately 130 to 180 gal of cooling water is required per 100 lb of ice produced. Therefore, a large amount of water is used not including the water needed to make the actual ice cubes. This is why air-cooled machines are preferred where applicable.

Flake ice production is a continuous process. The flakes are thin, randomly shaped, and mostly white or cloudy, but can be clear. Flake ice machines typically produced ice on a rotating evaporation drum. This drum operates at a lower evaporation temperature than in cube ice machines. This rotating drum can have refrigeration tubes on the inside and produce the ice on the outside, with an auger that removes the ice. The refrigeration tubes can also be located on the outside of the drum, forming the ice on the interior of the drum. The third production process has refrigeration between two cylinders/drums, which allows the ice to be formed on the inside or the outside of the drum. A benefit of this last process could possibly include the production of ice on both the inside and the outside at the same time. This may lead to a strain on the refrigeration system and require a longer freeze cycle, but ice production would be doubled without doubling the time or energy used. Other flake ice production processes replace the drum by using flat plates and flexible belts on which the water is frozen. However, the drum process is more common. Nuggets can be produced from the flake ice by compacting the flakes through tapered holes. Flake ice/nugget ice is colder than ice cubes because the harvest method does not require heat. This allows for easier storage of the ice.

An advantage of cloudy/white flake ice production over clear flake ice production is that cloudy/white ice production uses no bleed-off water is used to carry off

contaminants. All of the water is frozen, approximately 1 lb of water will produce 1 lb of ice. Clear flake ice requires much more water and energy, approximately 2 lb of water is required to produce 1 lb of ice. The production of clear flake ice compared to cloudy/white flake ice requires twice as much water and up to 50 percent more energy.

There are two types of water consumption for ice makers: the ice-making process itself, and the cooling of the refrigerant condenser (for water-cooled models). Facilities with ice-making machines should consider the following conservation actions:

- Ice flake machines generally use much less bleed-off water than ice cube machines and should be used wherever possible.
- Cloudy/white ice uses less water and energy than clear ice and should be used whenever possible.
- Where softened water is available, the soft water can be used to produce clear cubes with less bleed-off.
- Eliminate the use of single-pass cooling. Conservation measures applicable to once-through cooling water are discussed in the once-through cooling section of this chapter.
- Replace water-cooled ice makers with air-cooled units. These units may use slightly more electricity for operation, but conserve water. Because the useful life of ice making machines is usually only about 5 years, replacement of existing water-cooled ice makers with air-cooled models can be completed within a relatively short period.
- Install flow regulators to prevent excess flows through ice makers.
- Thinner ice cube production is more thermally efficient than thicker cubes.
- Operate the ice machine within its efficiency rate. If an ice machine produces ice up to this rate, the ice produced will be efficient. Ice produced above this level will require more energy and will be less efficient, but ice produced below this level will just use less refrigeration.
- Whenever possible, produce ice during off peak hours and store the ice for use during peak hours. This will save money on electricity.

In a case study of several commercial and industrial programs, Anderson (1993) discusses a restaurant that converted from a 400-lb water-cooled ice-maker to remote-air cooled. Consumption of water dropped by 70 percent. The ice maker had consumed over 75 percent of water used before the retrofit. At a cost of $577 to convert and a savings of $582/month (3,360 gpd), the restaurant achieved payback in 1 month. The conversion required that the piping of the water-cooled condenser

be retrofitted and connected to a remote-air cooled condenser. After 3 years of monitoring, the ice maker still functioned well and consumption remained low.

Other estimates similar to the actual case studies include the cost of water and energy as well as the initial cost of the ice machine. Three ice cube makers merit consideration: air-cooled, water-cooled, and remote air-cooled. The size of any of these ice machines would accommodate a restaurant seating from 325 to 350 people. The initial price of the water-cooled and air-cooled units are the same. The remote air cooled unit is slightly less in cost for the main unit, but with the addition of the remote unit, the price of that ice machine is more than the other two units. The ice production is approximately the same for all three of these units with difference of 35 lb of ice per day. Table 7 lists the approximate amount of water used per month by these machines. This table breaks down the amount of water and energy used per month by the ice machine including an estimated cost per month for usage. Our assumption of water costs is $1.25/kgal, while our energy estimate was $0.07/KWH. This estimate was using a standard levelized national average. The results back up the previous information. The best option for an ice machine is an air-cooled model. This unit has the least initial cost and the least cost to run.

Even though this is the cheapest and most efficient, the amount of water used in this machine is more than double what is required to produce ice. Considering that 12 gal are required to produce 100 lb of ice, this machine uses 25 gal of water. The water-cooled unit uses 31.2 gal while the remote air-cooled unit uses 38 gal. This information would lead us to believe that the water-cooled unit is the next most effective, but this is not true. The water-cooled unit also has the condenser water, which brings the amount of water actually used to produce 100 lb of ice to 189 gal. This unit wastes 177 gal of water in the process of making 100 lb of ice. Water is still cheaper than energy to the user, but the water-cooled machine is still more expensive due to the combined amounts of water and energy. The reduced amount of water and cost of usage of the remote air-cooled unit is paid back in less than 3 years. The warranty for the ice machines lasts 5 years with a larger approximate life span.

Table 7. Comparison of three ice makers.

	Water usage per month (gal)	Energy usage per month (KWH)	Monthly bill
Air-cooled	3675	855	$64.44
Water-cooled	29767	732	$88.45
Remote air-cooled	5643	909	$70.68

Figure 9 shows the payback period of this particular series of ice cube makers. The air-cooled is definitely the most economical while the remote air-cooled is the second best. This graph takes into account the initial cost as well as the cost of operation.

Flake ice machines are much more efficient. The initial cost of both the water-cooled and the air-cooled flake ice machines are the same. The production costs of the ice vary. Table 8 lists the water usage of the ice machines required to produce the same amount of ice (440 lb/day). The monthly bills are calculated using $1.25/Kgal and $0.07/KWH. The water-cooled unit uses an additional 7500 gal of water per month, while the air-cooled unit has 100 percent efficiency, every gallon of water used in the air-cooled machine becomes ice.

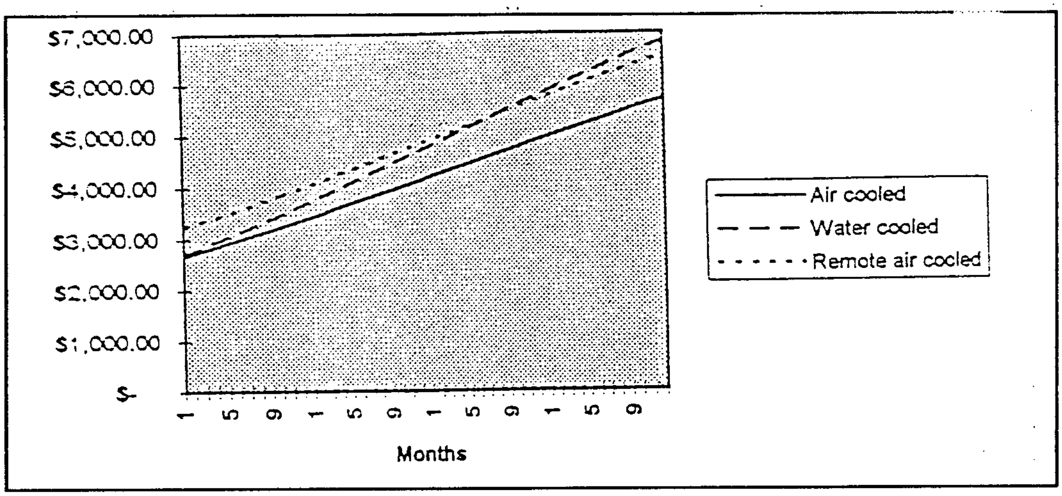

Figure 9. Payback period of ice cube makers.

Table 8. Comparison of flake ice machines.

	Water usage per month (gal)	Energy Usage Per Month (KWH)	Monthly Bill
Air-cooled	1584	594	$43.56
Water-cooled	9820.8	528	$49.24

12 Laundries and Clothes Washers

This chapter addresses various types of clothes-washing operations from large commercial laundries to horizontal axis washing machines, all of which have the opportunity save substantial amounts of water and energy as they become familiar to American homeowners and become lower in price.

Front-loading clothes washing machines are more efficient than top-loading ones. Typically, they use 30 to 50 percent less water and energy. This is because the horizontal mechanism (versus vertical for a top-loading washer) for clothes tumbling requires less water for cleaning and therefore less energy for heating the water.

Laundries

Laundries may be present on an installation or facilities such as the hospital. Several opportunities exist to conserve water:

1. Water may be conserved by optimizing existing equipment flows, installing water conserving washers, including continuous-batch type units, or installing water recycling systems. Water use in older commercial washers can be optimized by carefully monitoring the wash formulas and load types and sizes. Newer commercial washers are often more water efficient than the older units, especially continuous-batch or tunnel washers. These units require large quantities of laundry and careful sequencing of the washer loading. Water recycling systems that recycle both the wash and rinse water to subsequent wash loads are commercially available. These units offer both a water and energy savings due to the fact that the recycled water is heated and requires less energy to heat to operating temperatures required for the washer.
2. Consider replacing a conventional washer-extractor with a continuous-batch washer, which can save 60 to 70 percent of the volume of water and steam required if operated properly. Additional benefits can include energy savings, reduced maintenance costs, and reduced chemical usage. Minimize the need for resetting of equipment controls by carefully scheduling loads.
3. Be sure to wash full loads only.

4. Work with your laundry chemical supplier to develop programs requiring fewer rinse and wash steps. By changing chemicals or the washing program, you may be able to eliminate several fills of the washer-extractor for wash or rinse steps.
5. Save up to 25 percent of your laundry's water consumption by installing a rinsewater reclamation system. These systems provide computerized control, based on the laundry cycle, to divert rinsewater to a storage tank for reuse as washwater.
6. Save approximately 50 percent of your laundry's water consumption by installing a wash and rinsewater treatment and reclamation system. These treat wastewater from the laundry process to make it clean enough for reuse in initial wash cycles. These systems' treatment processes can include a combination of: settling, dissolved air flotation, filtration, chemical feed, and carbon adsorption.

Anderson (1993) describes water use activity at a large linen facility, which cleans 400,000 lb of laundry weekly using 3.75 million gal/month of water. Conservation methods include a contra-flow washer, a machine that does 4000 lb of laundry at a time and steps clothes from an optimum dirt and soap water solution to progressively cleaner water. The system is computer controlled. They credit efficient operation with a 50-percent reduction in water use. Before the changes, the facility used 7.4 million gal/month.

Horizontal Axis Washing Machines

Pugh and Samuel (1995) discuss the water saving potential of horizontal-axis (HA) washing machines. The potential exists for substantial energy, water, detergent, and wastewater savings through transforming the consumer's market towards the h-axis technology. In the United States, washing machines currently consume about 22 percent of indoor residential use of about 80 gal/capita/day, or 17.6 gal/capita/day for laundering. The h-axis machines could reduce the per capita consumption from 17.6 to 7-8 gal/capita/day. In addition to the water conservation aspects, the reduced loading on the treatment plants and reduced energy consumption are significant factors. H-axis machines currently dominate the European market while they represent only 1 to 2 percent of the American market. Initial demonstration projects have shown total water savings amounting to almost 60 percent. Average total water consumption per cycle was 18.7 gal for the HA and 60 gal for the existing vertical axis machine in one demonstration project in Seattle. Energy savings amounted to 63 to 73 percent. However, the actual energy savings will depend on the water temperature setting since the majority of the savings result from heating

less water. Extrapolating the consumption trends over a full year yields an annual operating cost savings of $150/unit. Undoubtedly, savings resulting from high efficiency washers will depend on the washers they replace and the clothes washer usage patterns. New standards and rules that would drive the American market toward high efficiency washers have great potential for significant water and energy savings.

Hill, Pope, and Winch (1995) present additional information on horizontal axis washing machines. They indicate that the average U.S. household with a washer purchased in 1992 used an average of 39 gal of water and 2.7 kWh/cycle (assuming 100 percent efficient water heat) for a total of 16,200 gal and 1,120 kWh annually. The 1994 Federal standards now require that new washers use 15 percent less water than the 1992 models. Most observers believe that the above figures overstate actual consumption since they are based on 1975 consumer laundering patterns, which have grown less energy intensive.

Unlike the typical vertical axis washer, which has a central agitator post and must have its wash tub filled with water for proper cleaning, the h-axis washer tub need be only partially filled with water for proper cleaning action. Clothing is tumbled through the wash solution approximately once a second by the rotating drum. Under typical usage, 80 to 90 percent of the energy consumption attributed to clothes washers is used to heat water. The partial filling of the h-axis washer's tub, therefore, results in significant reductions in total water, hot water, and water heating energy. Furthermore, recent models of h-axis washers have typically included high speed spin cycles that extract more moisture than is common in typical vertical axis washers. A lower remaining moisture content allows shorter dryer cycles. Shorter dryer cycles result in proportionate dryer energy reductions.

The Washington State Energy Office completed a technology assessment and cost-effectiveness evaluation of h-axis clothes washers in 1992. In general, the results showed h-axis washers with high spin speeds could use one-third less water, two thirds less energy, substantially less detergent, and reduce dryer time by one-third. The assessment suggested that certain cleaning and fabric care advantages might be associated with the tumble action of the h-axis design.

Laboratory testing confirmed expectations regarding energy and water use. Average, normalized energy use of the h-axis models was about half that of the vertical axis washer. Average normalized water consumption was about 20 percent lower. All h-axis models outperformed the vertical axis washer in a test of cleaning effectiveness.

13 Water Harvesting

A number of practices come under the subject of water harvesting. This chapter will review water harvesting in the broadest context, present a literature review of water harvesting, describe the use of rooftop catchments and cistern use, and finally describe water harvesting with an aim at using stormwater runoff from parking lots, for example, as an irrigation water source.

Water harvesting is a practice to capture stormwater runoff for beneficial use. In addition to surface capture of runoff, soil has a tremendous ability to treat water for removal of contaminants. Permeable or porous pavement allows water to infiltrate into the ground. More absorption and less runoff may allow storm drainage systems to be built smaller, thereby reducing capital expenditures.

In areas relatively untouched by development, with little surface covered by impermeable materials (pavement, hardstand) such as parking lots, roads, building complexes, etc., precipitation can percolate into the ground or runoff into surface waterways. Care must be taken, however, to avoid contamination of aquifers.

Increased levels of impermeable surface increase the stress on storm control systems effectively shortening the interval period for 10-year or 25-year floods enough so that these floods occur more frequently. Nonpoint source pollution is increased, flows runoff of the land surface faster, and erosion is accelerated. This further suggests the desirability of capture and use of stormwater runoff for beneficial use in addition to flood control.

Facilities around the country can use stormwater runoff from surrounding areas for irrigation. Anderson (1993) mentions an apartment complex that uses runoff from a nearby shopping mall. The system consists of a retention pond, a filtration basin, and a landscape irrigation system. When the retention pond is full, the water overflows into the sand filtration basin. Use for irrigation was estimated at 13 million gal annually.

A number of other water harvesting methods are useful for slowing, retaining, and storing runoff from exposed or land surfaces. They include:

- *Mulching*. Covering a soil surface with materials such as straw, bark, leaves, or branches. This forms a barrier of air and materials close to the soil, increasing its capacity to slow down and absorb water. As a side benefit, organic material (which helps retain water better) is added to the soil as these materials decompose.
- *Contouring*. Manipulating the ground so that water is slowed or directed to low spots for storage or absorption. Berms, steps, ditches, or terraces are examples of structures built to improve harvesting and reduce erosion.
- *Check Dams*. Building retaining walls out of materials in watersheds, i.e., branches and rocks, along with wire. These structures, made from wattles (brush) and weirs (gabions), obstruct water movement.
- *Sand Tank*. Storing water in the spaces between sand and other soil particles. In arid regions, water can be stored in the pores and then slowly released over time.
- *Paved Surfaces*. This procedure is useful for harvesting water in urban settings. Combined with pervious paving, this strategy serves numerous purposes. First, as water flows, it moves through the permeable surface, transferring into underground aquifers for recharge following soil treatment. Second, paved surfaces of parking lots, roads, and walkways can be contoured to direct remaining flow to green strips placed within or around porous paved surfaces. This greatly reduces storm drain runoff, and additional green areas are incorporated into paved areas, reducing the heat island effect and helping to purify urban air.
- *Paved Rivers*. Greenbelts can be created in urban areas by diversion of some of the water captured in paved natural rivers (a phenomenon found in municipalities in arid regions, i.e., Los Angeles), and use of the water for parks, aquifer recharge, reduced heat, and increased wetlands.

A cistern system for water harvesting is used at the National Wildflower Research Center near Austin, TX (Anderson 1993). Water for consumption is trucked to the site. Gutters are mounted around roofs of two greenhouses and the main office building, which feed the system. A filtering system was installed to siphon off the first wash from the gutters. Two 10,500 gallon storage tanks were installed with chlorination equipment and a sand filter. The water harvest system was estimated to save 182,000 gal/year.

Literature Review of Water Harvesting

Water harvesting is almost 4,000 years old. It most likely began in the Bronze Age, when desert inhabitants cleared and smoothed hillsides to increase runoff and built

channels to concentrate and collect the water and convey it to lower lying fields. This practice permitted agricultural-based civilizations to develop in regions with an average rainfall of about 3.9 in., an inadequate amount of precipitation to support conventional agriculture (National Academy of Sciences 1974).

Before 1950, relatively few systems were built, mostly by government agencies, to collect water for livestock and wildlife on islands with high rainfall and porous soils. The cost was usually high. In the 1950s, interest in water harvesting increased and more systems were installed. One of the most extensive is in Western Australia, where several thousand hectares of shaped, compacted earth catchments supply water for both households and livestock (National Academy of Sciences 1974). The performance of these water-harvesting systems is good when they are properly maintained. Extensive areas of asphalt or asphaltic-concrete catchments (600 ac.) also have been constructed to furnish water for 32 small towns in Western Australia (National Academy of Sciences 1974; Kellsall 1962).

Currently, rainwater harvesting is used mostly on a small scale, such as for farms, villages, and livestock. The land-alteration method is readily applicable for immediate use in selected areas worldwide. Australia and Israel already use rainwater harvesting technology. In the Sudan and Botswana, catchment tanks have been introduced in technical assistance programs (National Academy of Sciences 1974). Many island areas use roof-top catchments to provide water for domestic consumption. Astronomical observatories, such as Kitt Peak National Observatory in southern Arizona, are successfully harvesting and treating rainwater from asphalt parking lots and roadways for general uses, including drinking water.

Chemical treatments and ground covers remain experimental. Even though proven to be technically feasible and successful, they are not yet economically attractive enough to generate widespread use. Most soil treatments (especially the cheaper ones) have a limited lifetime and must be renewed periodically. They also require occasional maintenance because of cracking caused by unstable soils, oxidation, and plants growing up through the ground cover or treated soil. No one material has been proven superior for all catchment sites (National Academy of Sciences 1974).

Medina (1976) briefly discussed the use of concrete surfaces for catchment areas and noted that these are expected to last 20 years. Hollick (1982) did a very comprehensive review on water harvesting in arid lands, focused on Australian and U.S. research activities. He did not list the use of parking lots, but did provide a useful discussion of asphalt-coated catchments, where it was stated that the Public Works Department in Western Australia uses a design efficiency of 90 percent and a threshold value of 0.03 in. on relatively new asphalt surfaces. Extensive bibliogra-

phies of water harvesting/runoff farming and small-scale water management systems were prepared by Matlock (1983) and by Pacey and Cullis (1986). Zauderer and Hutchinson (1988) did a comprehensive review of water harvesting techniques of the southwestern United States and Mexico and did not note the use of parking lot areas although the use of asphalt catchments was mentioned.

Evans, Woolhiser, and Rouzi (1975) studied water harvesting from highways in Wyoming and concluded that this water could be used for livestock water, irrigation of forage, beautification of environment, or wildlife habitat enhancement.

A primer on water harvesting techniques and runoff farming was prepared by Matlock and Dutt (1986), including unit-cost evaluations for catchment and storage systems. Preul (1994) discussed water harvesting studies for the Kingdom of Jordan. He noted that water harvesting is an attractive alternative in arid areas facing acute water shortages. He illustrated two different configurations for rainfall-runoff water harvesting facilities from parking lots and/or impervious surfaces (Figure 10).

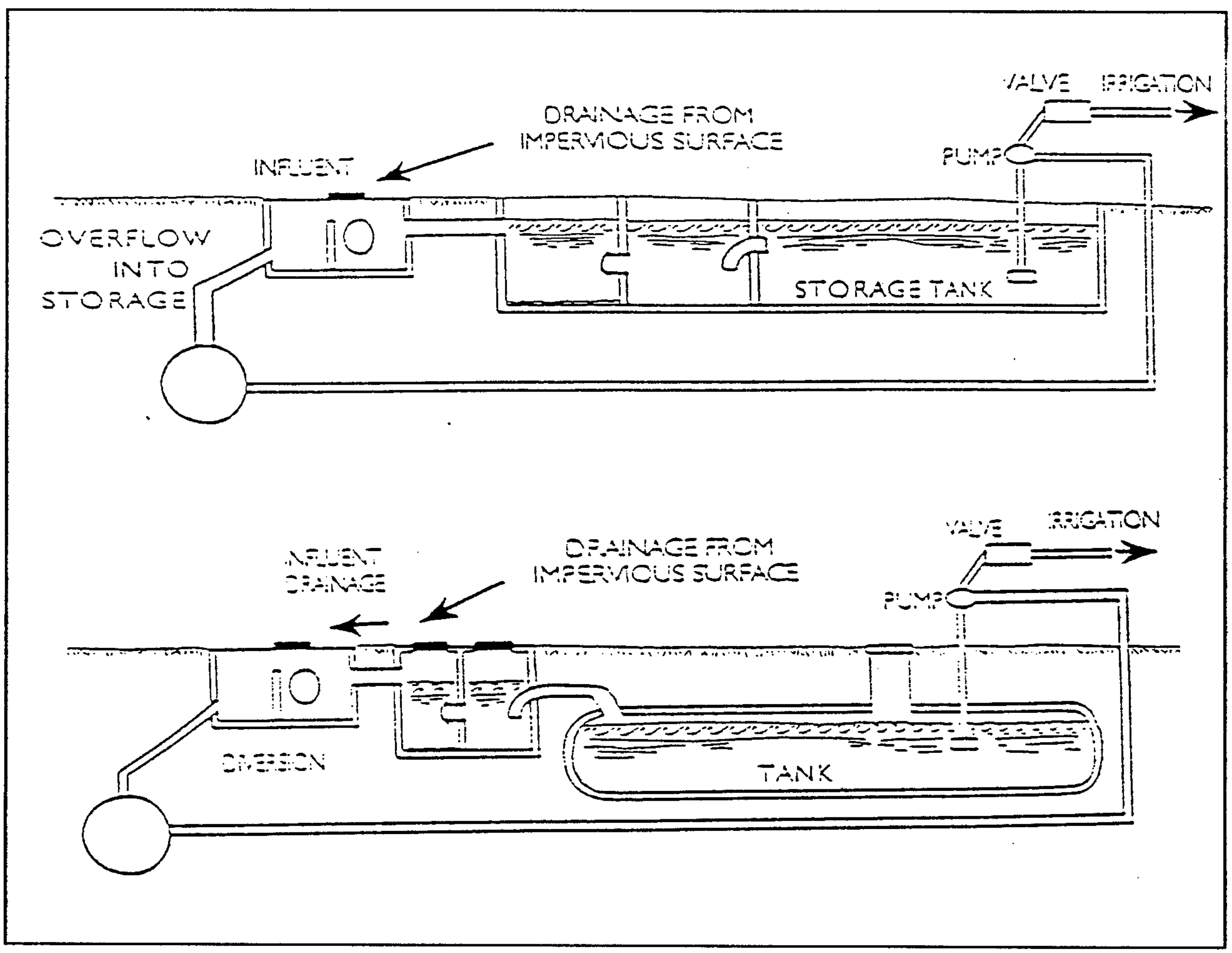

Figure 10. Rainfall-runoff water harvesting facilities for impervious surface drainage.

Precipitation and Flow Characteristics

Since rainwater harvesting depends on natural rainfall, it is only as reliable as the weather. Factors such as storm rainfall amount, intensity, frequency, and seasonal distribution determine harvesting feasibility and influence its efficiency. Also, care is required to minimize side effects such as soil erosion, soil instability, and local flooding. Soil erosion, a constant concern in water-harvesting systems, can be controlled if the slope is short and not too steep and if drains are suitably sloped. Slope also affects the quantity and quality of runoff. The most efficient harvest of water is from small, gently-sloping catchments, preferably at a grade of 1 to 5 percent (National Academy of Sciences 1974). However, expertise for designing rainwater-harvesting systems is limited. In many arid areas, no data exist on rainfall intensity and variability, which are needed to design an efficient system.

The total amount of rainfall is less relevant than are the rainfall characteristics of intensity, duration, and frequency. In arid areas, the variability of rainfall is very high. The effectiveness of a rainfall event depends on factors such as the length of the period between rainfall events. Of critical importance to water harvesting are the duration and intensity of rainfall. Runoff occurs only when certain thresholds are exceeded. Either the rainfall intensity should exceed the infiltration rate, or the rainfall intensity and duration should exceed the storage capacity of the catchment surface (e.g., parking lot surface) or soil. According to Bruins (1986), the threshold amount of rainfall required to generate runoff on slopes in arid zones is rather low. For stony soils in the Negev, for example, only 0.1 to 0.2 in. (3 to 5 mm) of rainfall is needed to generate runoff. The start of actual runoff is very difficult to predict. Rainfall simulation tests have shown a gradual range from infiltration without ponding at the surface to ponding and finally to runoff (Scoging and Thornes 1979).

A better indicator for the potential of water harvesting than the total amount of rainfall is the actual number of rainfall events that exceed the threshold and produce runoff. If storms of lower average intensities and shorter duration occur, the significance of this statement increases. Therefore, the major criteria for the potential of water harvesting are the frequency of individual precipitation events (Kutsch 1983) and the probability of a certain minimum amount and intensity. The frequency influences the so-called antecedent moisture condition, which indicates the decrease in soil storage capacity due to previous rainfall events (Reij et al. 1988).

The minimum amounts of average annual rainfall needed for water harvesting virtually all lie within the arid zone. However, on the basis of rainfall distribution in time, or more specifically, the erratic character of rainfall in the arid zone, the semi-arid zones are often cited as having a better potential for water harvesting

(Boers et al. 1986). The considerable variation in rainfall, which is so great in arid regions, also makes design of water harvesting structures difficult. Because structures need to be larger in these regions to collect greater depths of runoff, the potential damage caused by breaching in wetter-than-average years is also relatively greater.

More rainfall and a higher intensity produce more runoff and more favorable conditions for water harvesting. However, these two factors also increase erosion or at least the erosion hazard. Although Thames and Fischer (1981) stress that "erosion control is almost always an integral part, and often the primary objective of water resource management in arid zones," this link is very rarely made in texts on water harvesting (Reij et al. 1988).

Myers (1975, cf. Reij et al. 1988) concluded that the rainfall intensity, being much higher in the semi-arid tropics than in the temperate arid regions, is one of the main reasons that water harvesting methods developed in the temperate dry regions cannot be directly transferred to other areas.

At a higher elevation, which has a greater chance of having a rainfall event, and increasing the size of the drainage basin, more runoff would be produced in terms of absolute quantity (Thames and Fischer 1981). Smaller catchments produce a lower absolute amount of runoff, but they have a higher runoff efficiency (Boers and Ben-Asher 1985; Boers et al. 1986). According to Boers and Ben-Asher et al. (1985) and Bruins (1986), runoff efficiency decreased with larger catchment size as:

- the limited areal extension of showers reduced the average depth of rainfall occurring with a certain frequency
- the longer flow path increases "on-the-way" infiltration/evaporation and surface storage.

Shanan and Tadmore (1979) state that in the Negev, microcatchments up to 0.05 ac produced 0.4 to 1.2 in. runoff per year, whereas catchments of 740 to 1,240 acre did not produce more than 0.04 in. runoff per year. For semi-arid southeastern Arizona (average rainfall 14 in., Boughton and Stone [1985]) also observed a trend for decreasing annual runoff with increasing catchment area. For catchments greater than 25 ac, the transmission loss in the stream channels would be the major cause of runoff reduction.

These watershed characteristics and rainfall parameters must be borne in mind in planning or designing any rainfall/runoff harvesting facility. In the specific case of parking lots, however, the size of collection area is relatively small, generally one to

several acres, so that runoff concentration time is fairly rapid, and once beyond the threshold loss, abstractions (losses) en route to the collection point are rather minor.

System Components

A water harvesting system has been defined as "a system of catching and storing rainfall until it can be beneficially used" (Cluff 1967a). Such systems have been designed and operated for centuries, and the requisite design techniques are neither new nor particularly complex. The principal constraint in modern times has been the unit cost of water produced by the system. Economic feasibility depends heavily on the scarcity and comparative cost of alternative sources of water for its intended use.

A parking lot rainfall harvesting system designed for landscape irrigation contains the following basic components:

- rainfall harvesting surface (parking lot)
- runoff collection and concentration features
- water treatment devices (optional — discussed below)
- storage facility (optional — discussed below)
- water distribution and use facilities.

Evaluation of rainfall harvesting potential in a specific geographic area begins with initial field reconnaissance to familiarize the investigator with existing and potential catchment location, size, shape, slope, and runoff directions, along with an assessment of the availability of engineering design plans. The next step in implementing a rainfall harvesting project is the location and evaluation of specific physical sites where runoff could be diverted and used, followed by design and construction of facilities. The advantage of a demonstration site is that it permits a realistic assessment of actual costs and benefits, and the resolution of practical problems on an operational level, before entering into a large-scale program. The process of selecting favorable sites proceeds according to the following criteria:

- opportunity for multiple uses of runoff, and recharge potential, at larger sites
- adequate supply of runoff for intended uses
- favorable technical criteria
- minimal land purchase, excavation, and construction requirements
- presence of an existing park or other water-using facility, to which diverted runoff could be applied.

When a hardscape catchment, such as a parking lot, drains to desert soil, some of the runoff will be directly absorbed, thus reducing the potential usable volume. All collection features should be engineered to handle the maximum rainfall per unit time so as to provide for partial diversion to irrigated landscape areas and safe, efficient by-passing of unused flow.

Storage Systems

Harvested water can be stored in tanks or in reservoirs or as soil water in the root zone. Many systems store water in the soil itself (e.g., many terraces), but little research has been conducted on the storage of water in soil. In general, this method is less expensive and the water is less prone to evaporation than in systems with open surface water.

Some research has been conducted on the use of rock or sand fill to take advantage of some of the favorable properties of ground storage systems (Cluff 1975; Cluff and Dutt 1975). These techniques decrease storage capacity by about 50 percent, but greatly reduce evaporation losses.

If reservoirs are used to store harvested rainfall, seepage control and evaporation suppression become important to prevent the stored water from being quickly lost. Total seepage control can be achieved by storing harvested water either in tanks or plastic-lined ponds. Bentonite clay, as well as chemical sealants, have been used to reduce seepage from ponds (Dedrick 1975). Chemical sealants and common salt have been used to reduce seepage in soil-lined ponds (Dedrick 1975).

Tanks that are constructed without fills should be constructed to maximize storage volume and minimize containment and exposed surface area. Increasing depth, while holding exposed surface area constant, cuts down on the proportion of water loss to evaporation (Dedrick 1975).

Cluff (1981) conducted extensive research on the use of compartmented reservoirs to reduced surface area. This technique concentrates water by pumping water from partially filled compartments or reservoirs into a single compartment (Figure 11).

Methods of Evaporation Control

Three major approaches have been used to suppress evaporation: (1) application of chemicals, (2) use of floating devices, and (3) use of physical covers.

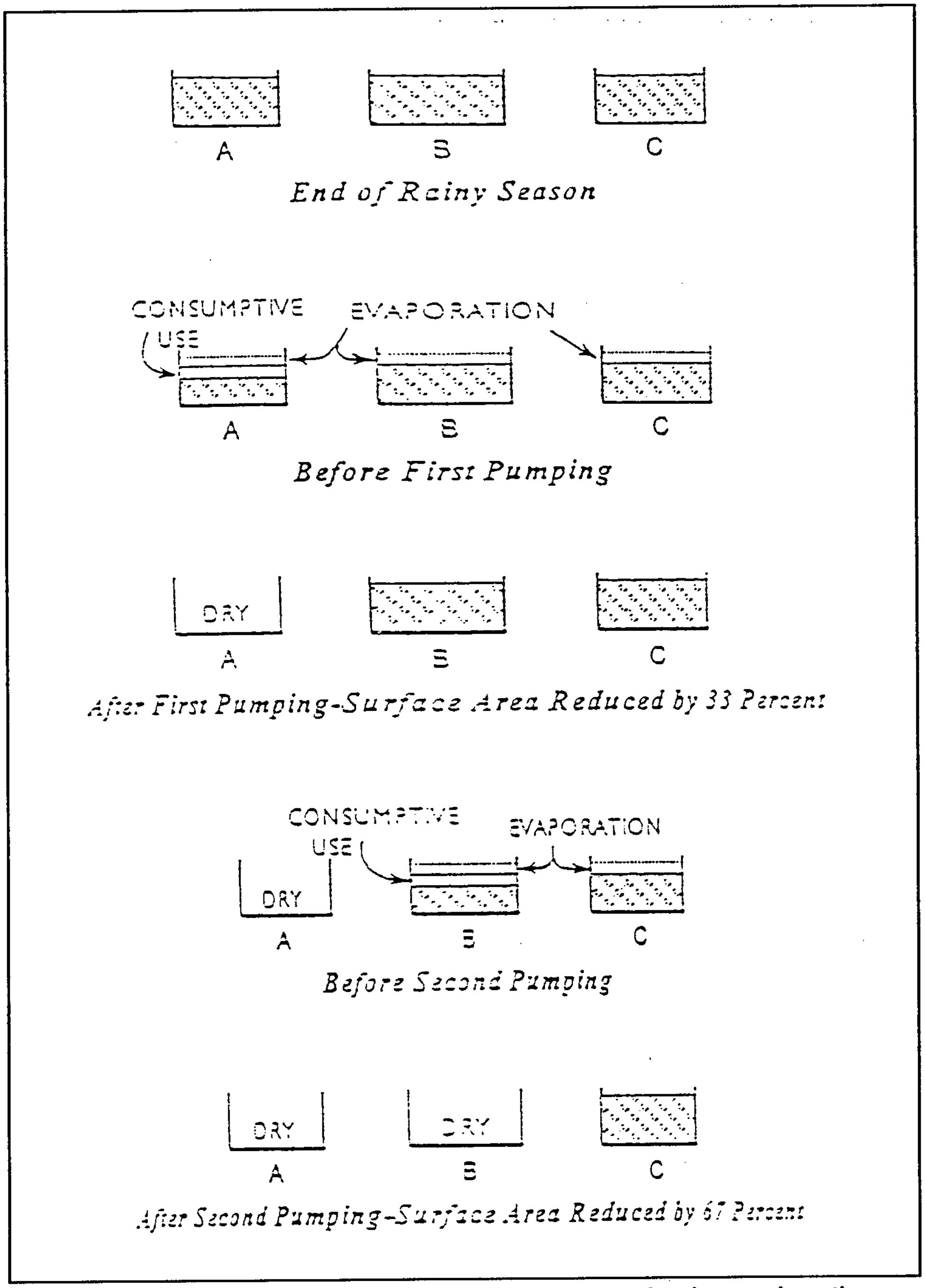

Figure 11. Three-compartment reservoir showing water levels at various times during the annual cycle of operation.

Application to Landscape Use

Land shaping can be very important in water harvesting. If the ultimate result is to capture and use the maximum amount of water, a concave landscape surface should be constructed instead of the traditional convex surface (Figure 12). Obviously, provisions must be made for those rainfall events that exceed the site's capacity to use or temporarily store the water that collects on the property. A spillway area from the storage tank is then necessary (Matlock 1985).

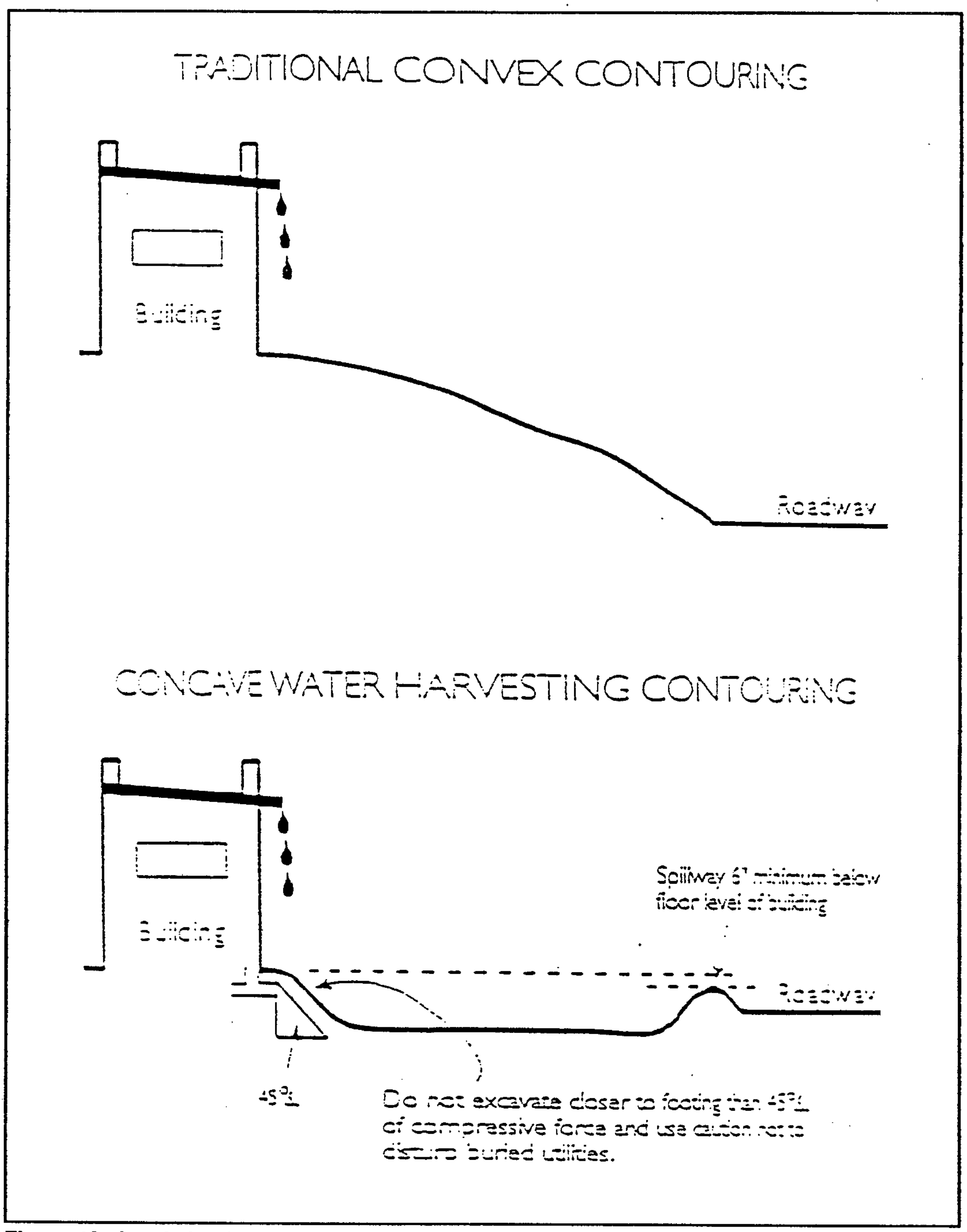

Figure 12. Land shaping for water harvesting from urban landscapes.

Proper plant selection has a lot to do with the success of a water harvesting system. Look at the areas or open spaces around the potential water harvesting site. Note the types of plants growing there and their natural spacing. Through water harvesting, the effectiveness of rainfall can be increased and plants of a higher rainfall zone can be grown, or the density of plant growth in a small area can be increased. Differences in plant communities as related to annual rainfall (which changes with elevation) are striking. Unfortunately, reliable data on water requirements of many landscape plants are limited.

Operation and Maintenance

Operation of a passive water harvesting system requires no more than observation at the right time. How did it work during a storm? Was there any overflow or breaking of dikes? Did all plants get their fair share of the water? For active systems, valves and controls must be used as flow occurs during the rain or later for pumpback and distribution (Matlock 1985).

Maintenance is a critical factor for any water harvesting system. Even a passive system requires some maintenance, and it must be carried out thoroughly and on a regular basis. Leaves, weeds and accumulation of trash are the most serious problems; they should be removed promptly. Dikes, berms, and channels should be cleaned and repaired whenever needed. Special treatment will be required to eliminate or control excessive erosion (Matlock 1985).

Water Quality

The quality of runoff water collected for any purpose should be investigated sufficiently to show its suitability for the intended use. Precipitation collects various constituents as it falls through the atmosphere. In urban areas, for example, lead and cadmium among other trace metals, may occur in concentrations that would exceed standards for drinking water (Brittain, DeCook, and Foster 1984). For landscape use, however, these substances are not generally a serious cause of concern. It is worth noting that the pH of rainfall is commonly on the acidic side.

Other sources of contamination may include particles from roofing materials (tar, asphalt), suspended particulates from the atmosphere or the collecting surface (dust and dirt), and microorganisms from bird droppings (fungi and coliform) (DeCook 1983). Overhanging trees may negatively affect parking lot runoff water quality by causing deposits of leaf litter and bird droppings.

Treatment of runoff, however, is commonly limited to primary methods, namely screening and simple field filtration. Once the runoff is diverted from the collecting surface, a simple method of treatment may be desired. Popkin (in Resnick, DeCook, and Phillips 1983) has evaluated a low-cost field treatment process for urban storm runoff. In that process, runoff diverted from a local watercourse was passed over common grasses and through a profile of native soil. Samples of the diverted and treated water were analyzed following eleven storm runoff events during a 1-year period. Table 9 lists the principal water-quality constituents of concern and the average change in each following grass and grass-soil filtration.

A sediment trap or settling tank should be provided preceding the filtration treatment, and chlorination may be recommended following the treatment, especially if the product water is destined for recreational uses involving human contact, such as a playground. Caution must be taken if chlorinated water is used since it may be harmful to plants. The concentration of chlorine used should be based on the quality of the water desired. Grass-soil filtering, as indicated, yields a higher quality of water than simple grass filtering. However, the grass filtration is generally adequate for recreational uses and it may be preferred because of lower costs and faster treatment rates (DeCook 1983).

Rainfall Harvesting Through Cisterns

Conceptual Design

Rainfall harvesting through the use of a cistern was evaluated for Army application. The rainfall harvesting concept contains three major components: (1) the rainfall-runoff collection system that concentrates water and directs it toward the storage facility, (2) the storage tank (cistern) for interim retention of water between storm

Table 9. Average reduction in concentration (percent).

Constituent	Grass	Grass-Soil
Chemical Oxygen Demand (COD)	62	99
Suspended Solids (SS)	35	99.6
Volatile Suspended Solids (VSS)	26	97
Turbidity	97	99.8
Total Coliforms	84	98
Fecal Coliforms	87	99.8

rainfall events, and (3) the distribution system that conducts the stored water to points of use as needed (Figure 13).

Site Selection

A suitable site for the installation of these components would have the following set of site selection criteria:

- a site where a significant quantity of rainfall/runoff can be readily collected and stored in the cistern
- a site that has, or is suitable for, a designed landscape served by an irrigation/distribution system to which the stored water can be pumped for demonstrating operational characteristics of the cistern and appurtenant facilities
- a site where monitoring of the cistern operation can be performed readily.

Rainfall Collection

The following are the major components of a cistern system (cistern [manufacture], gutters, installation [cistern, plumbing, electrical], and landscaping).

Materials. Fiberglass was chosen as the preferred construction material for the cistern, in consideration of cost, durability, and portability related to size and weight. Other options evaluated for construction materials included concrete and steel tanks. Fiberglass is quite practical in terms of transportation and installation as well as unit cost, which runs in the range of $1.00 to $1.25 per gallon of storage capacity. Note that storage is typically the most expensive aspect of any water harvesting system.

Hydrologic Design. The design of the cistern storage system is influenced by numerous factors. The fundamental hydrologic considerations are the available supply and probable demand for the stored water, both in seasonal terms. Modifications then must be made for cost considerations, anticipated benefit, adaptability of the cistern system to the site (feasible cistern size, excavation volume and soil conditions, and site drainage), and aesthetic value to occupants, visitors, and passers-by.

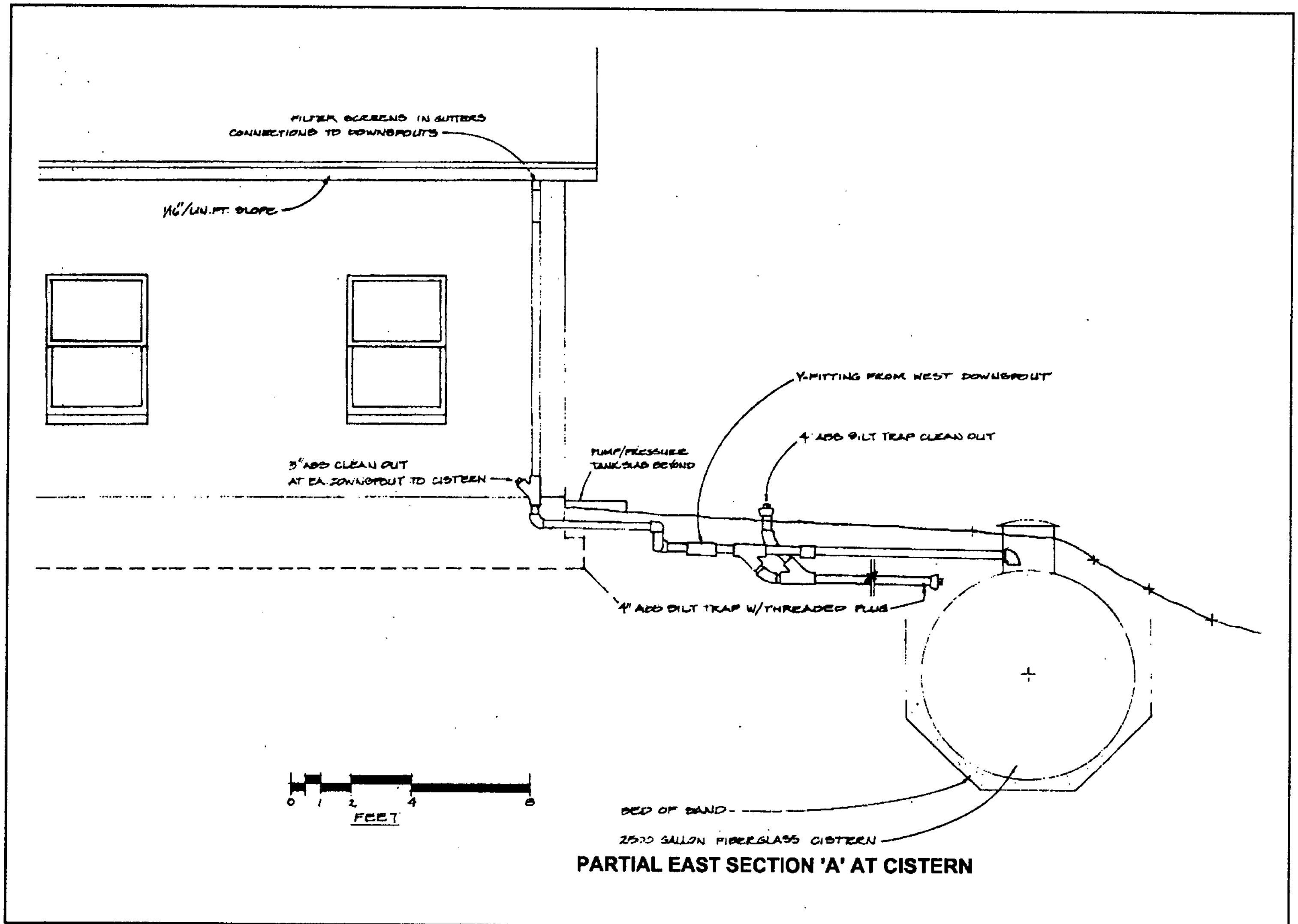

Figure 13. Example cistern for rainfall harvesting.

A hydrologic design may be geared to various objectives. For example, the objective of capturing, storing, and using all available rainfall under all conditions may require an inordinately large cistern size and could incur disproportionate costs for storage in relation to water demand for beneficial use, exceeding a justifiable budget or available funding for such a project. Accordingly, the gross size and hydraulic capacity of the design used herein represents a more moderate size and scope. In general terms, the landscape plant irrigation requirements will be relatively modest and will be met in most years without total depletion of water in storage. Conversely, however, excessive rainfall intensity, duration, or frequency — especially in late summer storms — could result in overflow of the system. Safe and efficient drainage of any overflow is provided for in the site plan.

The first hydrologic design parameter to be considered is the expected quantity of rooftop runoff per year and by month. From the monthly and annual average rainfall amounts, factors of water yield in gal/sq ft of rooftop can be determined.

The approximate annual water supply from rainfall having been determined, it is necessary to estimate the water "demand," or simply the irrigation water requirement of the designed landscape, for the year and through the seasons of the year. A precise quantification of the composite plant water requirement is quite tenuous, but useful approximations can be made. First, it must be noted that water needs of landscape plants in an arid or semiarid climate can vary greatly depending on temporal weather conditions, soil structure and fertility, plant maturity, and numerous other factors, including individual plant variations.

Note that for many plants, higher water application rates may be required during the initial establishment period.

Installation. Take maximum advantage of site-specific conditions to minimize excavation and waste hauling from the site. Use sound construction technique including bedding as appropriate to minimize punctures from rock. Excavated earth was used to cover the cistern up to a level exposing only the manway, cistern vent, and the 4-in. diameter ABS cistern overflow pipe to daylight.

Appurtenant Hardware. Following placement of the cistern, all connections and appurtenant fixtures were installed. Three-in. ABS pipes were brought underground from the two principal downspouts to a junction from which 4-in. piping extends to the cistern. This latter pipe contains a branch with a clean out to grade and silt trap with an easily accessible and removable end cap, which can be flushed as needed. Where the 4-in. conveyance pipe enters the cistern and within

easy reach through the manway, is the filter basket for trapping larger debris that could potentially plug the overflow and/or the foot valve and damage the pump.

Extending downward beside the manway is a PVC supply pipe fitted with a foot valve near the bottom of the tank. A compression coupling easily accessible from the manway enables removal of the foot valve for cleaning and maintenance as required. In similar systems to date, foot valves have not required any service, but this fitting is a good precautionary measure. A mercury switch also is provided to cut off power to the pump when the stored water level reaches a low point. This switch protects the pump from running dry and potentially burning out. The mercury switch and pump have been wired through an electrical relay that illuminates a red warning light located inside the building when a low water level exists. Depending on circumstances, i.e., season and landscape irrigation needs, municipal water can be added to the cistern through the manway, enabling the pump to supply the irrigation system, or the light can be ignored until collected rainfall fills the cistern to the point where the mercury switch closes and the light goes off automatically. The pump directs the stored water to the 32-gallon pressure tank from which water is supplied to the drip irrigation system in the landscaped area.

In the event of excessive rainfall and inflow to the cistern, a 4-in. ABS overflow pipe goes to daylight with a screened outlet.

Water Distribution and Use. The pressurized water supply from the cistern is piped to the several drip system outlets to supply planted areas. This system can be energized as required for irrigation of plants, according to preset irrigation schedules and/or by visual monitoring of plant conditions under various weather regimes. If the cistern water supply becomes depleted, storage must be augmented by garden hose from the building's internally-plumbed water supply. The system consists of ½-in. polyethylene supply lines and individual emitters placed at each plant. The system is controlled by an electronic Hunter SRC controller that has a 365-day calendar clock, as well as a rain sensor bypass and individual solenoid valves. An in-line filter is ahead of the emitters to prevent clogging.

Landscape Concepts

The entrapment and funneling of rainfall for beneficial use by plant materials is encouraged throughout the landscape design. The depressed, concave lawn area encourages the containment of run-off, allowing the water to percolate down to the plant root zone. A rock-covered swale could be used in the southeastern corner of the building in the flower bed under the roof eaves without gutters to promote

greater infiltration of rain into the underlying soils, which would serve as storage. Rocks used as a ground cover also allow advantageous use by plant roots of rainfall that is caught and stored in crevices under and between rocks. These rocks also conserve moisture, acting as mulch to prevent evaporation.

Of utmost importance to the success of a landscape plan is the ability of selected plant materials to survive and, hopefully, even thrive under the local precipitation regime, placing no additional burden on water resources for landscape purposes. Therefore, regional plant species adapted to local climatic conditions and precipitation events were selected for use in the landscape plan.

Irrigation Requirements

Following plant selection, estimates of each species' annual irrigation requirements are presented and the total water requirement from these estimates is determined.

The available storage volume in the cistern is only 2,500 gal. Therefore, the day-to-day and month-to-month operation of the cistern system must include a judicious scheduling of augmentation and withdrawals from storage.

Operation and Maintenance

The operation of the water supply system, once installed, is virtually automatic since rainfall collection and diversion to the cistern operates by gravity. The system of water distribution from the cistern to the landscape plantings will be operated by pre-set timers. When cistern storage volume falls below a predetermined level, the alarm inside the clinic will alert key personnel who will have been briefed on system operation.

Maintenance of the supply system will entail periodic inspection of the eave gutters and downspouts to check for clogging, and occasional cleaning of the filter basket on the incoming line. Maintenance of pumps and electrical equipment should follow closely the manufacturer's specifications for care of that equipment.

Steps to clean the silt trap include:

- open clean-out
- remove and unscreen plug
- remove plug at daylight opening
- inspect for silt

- "snake" with dry cloth and snake tool
- flush briefly with water and recapture water in bucket. Strain out silt and return clean water to cistern.

Costs and Benefits of System

Landscape irrigation water can be provided for $1.82 per 1,000 gal from the domestic water supplier on the post. In an average year, 16,200 gal of rainwater could be collected from the building's rooftop. Therefore, the total cost of buying an equivalent quantity of water for landscape irrigation would be [$1.82/1,000 gal × 16,200 gal] or $29.48/year.

The cost of building a collection and water storage facility was $8,511 (Table 10). Simple interest on the investment in the system is [$8,511 @ 6 percent] or $510/year. Depreciation on the facility is calculated at $682/year. Total annual costs for interest and depreciation for the cistern, gutter, and distribution system are calculated to be $1,192/year or $73.58/1,000 gal.

If the cost of purchased versus collected irrigation water is compared from a purely economic standpoint, irrigation water can be purchased for $1.82/1,000 gal. Collecting water from the building roof and storing it would cost slightly more than $73/1,000 gal.

Since the principal (groundwater) supply in the region is finite, its value will increase sharply in the long term, as will the cost of providing it. For the near future, however, its cost will remain appreciably below that of harvesting and storing rooftop runoff.

At present levels of cost for materials and labor, the cistern storage system is technically feasible, but economically infeasible, since costs greatly exceed tangible benefits.

The cost of using either rooftop or parking lot runoff without storage, however, is much more moderate, since the storage component is the singlemost expensive part of the system. Parking lot runoff use is discussed further in this chapter.

Table 10. Water collection and storage facility cost.

Collection Facility	Cost
Gutters on building	$636
Cistern	$3,375
Distribution system	$4,500
Total	$8,511

The benefits of water harvesting for landscape irrigation are difficult to quantify directly. If the captured water provides an essential ingredient for a recreational area, analytical methods are available to evaluate the outdoor recreation experience generated by the water-based facility. However, to the extent that the water contributes only to beautification through plant irrigation, the aesthetic results are intangible.

Parking Lot Rainfall Harvesting Feasibility

A prototype parking lot rainfall harvesting system was evaluated for a site at a southwestern Army installation, which would yield an average of 159,000 gal of runoff per year. Beneficial use of much of this water could be made for enhancement of the adjoining greenbelt area, with only minor expenditures for runoff control structures and/or ground surface modification for concentration of runoff in planting areas.

Overview of Parking Lot Rainfall Harvesting

The use of parking lots and/or other hard or paved surfaces for harvesting rainfall is a technologically-proven alternative for obtaining water supplies (Figure 14). This water can be used for various purposes ranging from landscape irrigation to drinking water, depending on the methods and levels of treatment. The suitability of rainfall harvesting systems depends on their geographical location and the seasonality, as well as the amount of precipitation. In addition, the cost of harvesting, storing, and treating rainfall needs to be evaluated for individual sites in comparison with the cost of alternative water supplies.

This section will present a feasibility report regarding the use of parking lot runoff for landscape irrigation on a military post. In a larger context, a complete water resources "project" might contain the following elements, after project authorization and initial funding:

- field site evaluation, surveys, and data collection
- data analysis and conceptual design
- feasibility study
- engineering design plans and specifications
- construction, supervision, and inspection
- operation and maintenance
- monitoring and evaluation.

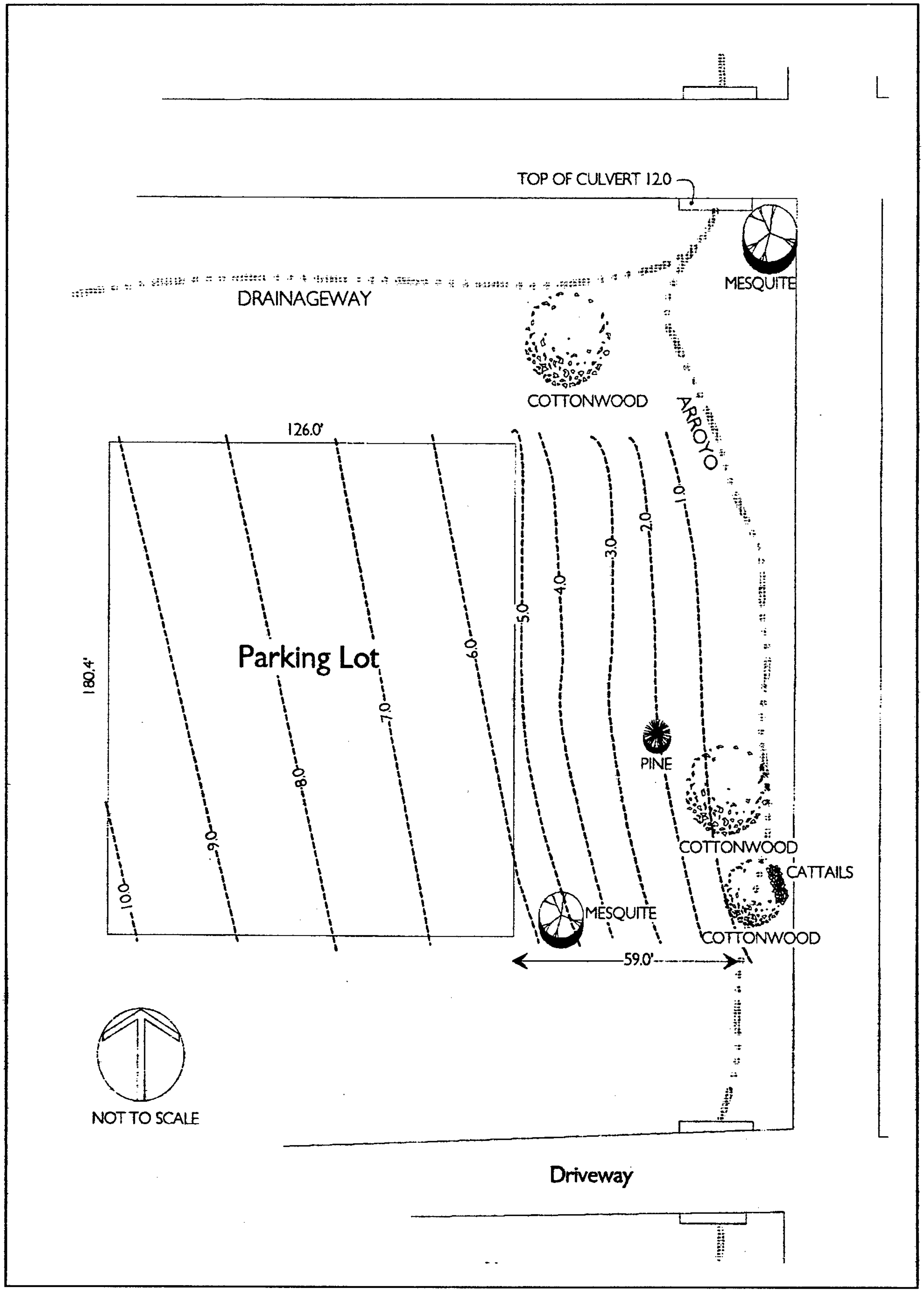

Figure 14. Example parking lot rainfall harvesting design.

The feasibility report (element 3) is commonly preceded by preliminary performance of elements 1 and 2 and a projection of elements 4 through 7, so that the feasibility study becomes a representation of the entire project, but on a miniature, or "prototype," scale. Such a perspective is the basis of this section.

The feasibility study itself may contain several aspects, as follows:

- Technical feasibility
  - Physical/structural/hydrological design concepts
- Economic feasibility
  - Project costs and benefits
- Institutional feasibility
  - Legal and political constraints
  - Social/cultural acceptance
  - Environmental considerations.

This section will consider the technical and economic aspects and will identify basic environmental aspects. The remaining subjects listed above are believed to be "in-house" matters, since the studied project presumably would be installed within a military post, and are not covered in this discussion.

Selection of Prototype Site

Selection was based largely on the following criteria:

- The boundaries of the lot are topographically well-defined so that the rainfall harvesting area and the runoff discharging boundaries can be sharply delineated.
- The runoff yielded by the parking lot can be readily controlled and concentrated in desired locations, with very little physical modification or expense.
- A grassed area with several existing trees, lying downslope from the parking lot, can be readily adapted to water distribution and use by means of modest landscaping improvements, with excess runoff diverted to an existing drainageway.
- The site is adjacent to a main thoroughfare, near both residential and business areas, and thus has excellent visual exposure to the public.

Harvested Water Supply

Monthly and annual quantities of runoff from the parking lot can be estimated from average monthly and annual precipitation data, employing the formula for estimating rooftop runoff, but using an appropriately modified runoff coefficient and threshold loss factor. An annual water yield of 159,000 gal is available for irrigation of the nearby park-like "greenbelt" area.

Runoff Collection and Use

The concentration, collection, and detention of runoff depends on the pattern of water use desired. Landscape vegetation plant types and density, together with topographic configuration, will determine the pattern of water distribution. If fully-grassed areas are desired downslope from the lot, for example, a curbing would be installed along the entire eastern boundary of the lot, with multiple screened openings to induce even water-spreading along its length. In places where a more concentrated water application is needed for trees, bushes, or gardens, simple earthen berms can be formed and the surface sloped toward those points.

Where occasional excess runoff occurs, detention storage is an option. The construction of a storage facility is not included in this discussion because the cost of storage space proportionate to the runoff available would be relatively high. Where storage is desired, an evaluation must be made in terms of benefit versus cost of storage or in terms of alternative costs of water, relative to the irrigation requirements of a specific landscape plan. For the present prototype study, it was proposed that runoff be diverted, retained in transit as needed, and applied to plantings with all additional quantities of water being by-passed.

Technical Feasibility

The physical and hydrological parameters of the existing site are amenable to designing a runoff harvesting site. The rainfall collection area is in place and will produce 159,000 gal of runoff in a normal precipitation year. Water control structures, as mentioned in the preceding section, would be minimal. Any practical landscaping design created for the runoff-receiving greenbelt area would be amply served by irrigation from the runoff received.

Economic Evaluation

Economic considerations must include both capital costs for installing the runoff harvesting system and operation/maintenance costs for sustaining it. Both fixed and variable costs for the system visualized here are relatively low. If initial fixed costs exceed perceived benefits in the first year, such costs can be annualized or amortized over the expected life of the project. Evaluation of benefits may be complicated by the intangible aspects of aesthetic values and recreational benefits in the use of the landscape area.

The benefits of water harvesting from parking lots for landscape irrigation are difficult to quantify. For a large-scale recreational area, analytical methods could be used to evaluate the outdoor recreation experience generated by the water-based facility. However, in this small site, the water contributes only to beautification through plant irrigation, and these aesthetic results are intangible.

In summary, this chapter has presented information on water harvesting including an overall review and two more specific applications, the use of roof top collection with cisterns for irrigation, and collection of parking lot runoff for irrigation use. Benefits are difficult to quantify due to intangibles. Both options are technically feasible. However, the cost of storage for the cistern system renders it economically infeasible until the value of water increases substantially.

14 Graywater

Graywater (Prillwitz and Farwell 1995) is a potential resource that is not widely used. Graywater is defined as untreated household wastewater that has not come into contact with toilet waste. It includes the wastewater from bathtubs, showers, bathroom washbasins, laundry tubs, and clothes washers. It does not include water from kitchen sinks or dishwashers, due primarily to the grease content of water from those sources. Graywater has been and is widely used, primarily in rural areas (mostly illegally, as plumbing codes usually require drain water to be discharged into a sewer or septic system). It is most commonly used for residential landscape applications, but can also be used as flushwater for toilets and urinals. However, drought-induced water shortages and rationing has caused many homeowners to take matters into their own hands and, under the circumstances, officials tend to "look the other way." California was one State that established graywater use standards. A number of other States have standards as well.

Graywater use was legalized because:

1. Thousands of bootleg systems were in use, creating a desire to provide guidance and legal avenues for better health.
2. The need to use water more efficiently has grown as the supply has shrunk.
3. Graywater provides water suppliers and homeowners with more flexibility to supply secondary water needs, such as lawn watering. (Landscapes often embody 5 to 10 percent of the value of a home.)
4. Graywater standards can provide economic opportunities for manufacturers and installers

A Graywater Guide was developed for California (Appendix B). The seven steps (Prillwitz and Farwell 1995) are:

1. Investigate the permit process.
2. Gather information: how much produced, how much landscape can be irrigated, plot plan, construction details.
3. Design the system: plumbing: pipes and valves to bring the graywater out of the house; a surge tank to temporarily hold large drain flows from washing machines or bathtubs; a filter to remove particles; a pump to move water from

the surge tank to the irrigation field and an irrigation system: either subsurface drip or mini-leach fields.

4. Get a permit.
5. Install the system.
6. Arrange for system inspection and approval.
7. Use and maintain the system.

In a graywater system, water that would normally be discharged to the sanitary collection system is collected, treated and reused. The basic steps are:

- Collect wastewater.
- Pipe the water to a treatment unit, which can be physical, biological, or chemical.
- After filtration, store the water and pump it to its ultimate end-use, where it is regulated by a valves and controls.

System Components

Graywater systems range from simple, residential applications to complex fully automated commercial and industrial systems. Regardless of their complexity, all graywater systems include most or all of the following elements:

- storage tank(s) (typically fiberglass or industrial-strength plastic)
- piping (color-coded PVC)
- filters (polyester, cloth, and the like)
- pump (fractional horsepower)
- valves (three-way and check)
- controls (manual or automatic).

Collection Methods

For buildings with slab foundations, recoverable graywater may be limited to washing machine discharge, because most drain pipes (such as for sinks) are buried beneath the slab and thus not easily accessible without a significant additional expense. However, buildings with perimeter foundations permit access to piping from crawl spaces, enabling recovery of most graywater sources.

Treatment Methods

Graywater treatment methods include media filtration, collection and settling, biological treatment units, reverse osmosis, sedimentation/filtration, and physical/chemical treatment. Depending on the graywater source, application, recycling scheme, and economics, one method may be more appropriate than the other. These methods are discussed below.

Media Filtration

Filters made of nylon, cloth, sand, or rocks, and gates can all be used for graywater filtration. A nylon or cloth filter system consists of a filter bag connected to the graywater inlet pipe. The graywater is passed through the filter media, collected, and typically pumped to a mini-leach field (an underground gravel filter) for irrigation uses.

Some filters use a sand- and rock-filled tank. In these systems, graywater is poured onto splash plates, where it then seeps through the filter media. Bacteria growing on the sand break down the organic matter in the water and extract nutrients, which prevents further bacterial growth. Other types of filters used to treat graywater include filters that use pea-sized stones instead of sand, diatomaceous earth filters, and rack or gate filters, which can be used to remove particulate matter.

Collection and Settling

Collection and settling systems employ techniques commonly used for treating combined graywater and blackwater. For example, one such system uses a septic tank. Solids from the incoming graywater settle to the bottom sludge layer and other materials, such as grease and hair, form an upper scum layer. The remaining effluent liquid then flows through an outlet pipe for further treatment.

Biological Treatment Units

Biological treatment units usually comprise three chambers: presettling, aeration, and final settling (with sludge return). Graywater flows into the presettling chamber, where solids settle out. The remaining effluent then flows into the aeration chamber, where biological action reduces soluble organics. In the final

settling chamber, biologically active solids settle out. These treatment units are usually used in commercial applications.

Reverse Osmosis

Reverse osmosis units have been tested for graywater treatment. These systems comprise storage tanks, pumps, filtration units, and a reverse osmosis module. The water is collected, filtered, and then pumped into the reverse osmosis unit.

Sedimentation/Filtration

There are a variety of sedimentation/filtration treatment systems, most of which have a conically shaped storage/settling tank and a filter. A variety of filters can be used, ranging from easily discarded cartridge filters, to diatomaceous earth filters, to activated charcoal filters.

Physical/Chemical Treatment

In physical/chemical treatment, graywater flows through a rapid mix tank, where polymer and activated carbon are added. The mixture of graywater, polymer, and carbon flows to a clarifier, where a sludge conditioner is added. After settling, the remaining water is disinfected and passed through a diatomaceous earth filter.

Disinfection Techniques

After graywater is treated, it may then also be disinfected. Four different disinfection techniques may be used to treat graywater for reuse within or outside buildings: ultraviolet irradiation, ozone, chlorine, and iodine. These are mentioned below.

Ultraviolet Irradiation

Ultraviolet (UV) irradiation disinfection involves passing graywater under an ultraviolet lamp to kill microorganisms. For effective disinfection by UV, graywater must be free of particulate matter.

Ozone

Ozone is a highly reactive form of oxygen that is formed naturally when the sun's shortwave ultraviolet light reacts with oxygen in the upper atmosphere. Disinfecting graywater by exposing it to ozone is very safe and can destroy algae, bacteria, and viruses, and can oxidize most organic and inorganic contaminants. While ozone in large doses can be harmful to humans, a well-designed ozone system for graywater disinfection poses no harmful or irritating problems.

Chlorine

Chlorine tablets are the most commonly used method of graywater disinfection in residential applications. Bacterial reductions occur after about 30 minutes of exposure to the chlorine.

Iodine

Iodine crystal units operate in the same manner as chorine tablets. However, because of iodine's limited solubility, a dosing pump is required to ensure adequate pressure and flow of wastewater for the iodine crystals to dissolve.

Storage

After treatment, graywater can be stored for no more than 48 hours. Water that cannot be used by this time must be discharged to the sanitary system.

Installation Considerations

Graywater systems must be installed in accordance with local plumbing codes and should be by professional, licensed contractors. Installing a graywater system requires the retrofitting of existing plumbing, and all alterations to the plumbing system may have to be approved by local authorities.

Areas that permit graywater recycling may require building inspectors to inspect sites and after installation, verify compliance and proper operation of the graywater system.

Graywater supply systems should be clearly distinguished from potable water supplies. Methods of doing so may include extensive labeling of the system or the use of different piping materials for the different systems. All graywater outlets must be clearly labeled to indicate that they dispense nonpotable water. Local codes may also require marking graywater supplies by adding biodegradable dye. Additionally, backflow preventers also must be installed to ensure the proper separation of potable and graywater supply systems.

Operation and Maintenance Considerations

The pathogenic organisms in graywater must not come into contact with either humans or animals. There are several precautions to ensure this does not happen. First, either treat the water to eliminate pathogens or avoid their introduction into water by not mixing graywater with potential fecal matter sources. Second, prevent human exposure to the graywater by not collecting or storing it in an open container.

Graywater used for irrigation should not be applied directly through a spraying device, but rather injected directly into the soil through drip irrigation, which allows the benefits of using recycled water and avoiding contaminating animals, humans, and edible plants.

It is also important to make sure that cleaning products found in the graywater do not contain chemical levels that could poison plants or damage soil through the buildup of inorganic salts. Biodegradable cleaners that contain no sodium, boron, or chlorine can be safely used with graywater systems and are commercially available.

Rain or excessive irrigation could cause ground saturation and result in pools of graywater on the surface. To help eliminate this situation, turn off the graywater system and divert the graywater to the sanitary sewer line during rainy periods.

A maintenance program for a graywater system must include the following steps, all of which must be performed regularly:

- inspecting the system for leaks and blockages
- cleaning and replacing the filter bimonthly
- replacing the disinfectant
- ensuring that controls operate properly
- periodically flushing the entire system.

15 Irrigation and Landscaping Practices

Concern for the environment, protecting natural resources, reducing maintenance, improving long-term sustainability, and ultimately, saving money are major reasons to design and develop water conserving landscapes for U.S. military installations. Nationwide, recent data indicates that about 50 percent of all domestic or residential water use goes into landscape maintenance (Ellefson, Stephens, and Welsh 1992). Water has often been viewed as an abundant, inexhaustible, and inexpensive resource. In recent years, however, water shortages, concerns about groundwater depletion and pollution, mandatory rationing during extended periods of drought, and increased supply costs have begun to change these attitudes concerning water. Developing additional water resources to meet future demand is expensive and not cost effective (Sanders and Thurow 1982). A more sensible, cost effective alternative to developing additional supplies involves conserving water by reducing demand for it. Because landscape maintenance currently consumes significant amounts of water that might be used for other competitive purposes, it makes sense to pursue strategies that conserve water through landscape design, development, or renovation. Several seemingly small practices such as mulching, soil improvement, and appropriate plant selection have already been shown to save an estimated 30 to 50 percent of the water normally being used for landscape maintenance (DeFreitas 1993). In a memorandum dated 26 April 1994, the President directed a series of actions to increase environmentally and economically beneficial landscaping practices at Federal facilities. DOD policy is to use regionally native plants and grasses to the maximum extent feasible to reduce maintenance requirements and water consumption.

Behavioral changes are also appropriate. Green lawns year-round are a luxury in some areas. Plants should be allowed go dormant. Sprinkler systems should be controlled to ensure that watering is not done during rains and that streets and sidewalks are not watered.

This chapter provides water conservation guidelines addressing landscape design, development, renovation, and maintenance activities for U.S. military installations. This guidance is applicable to all U.S. military installations. The guidelines presented should be useful in helping the U.S. military conserve significant amounts

of water and concomitantly reduce costs associated with landscape design, management, and maintenance.

The information and guidelines in this report can be used by installation or contract personnel for planning, designing, and implementing water conservation practices on the various types of improved landscapes located within a typical U.S. Army installation.

Principles of Water Conservation in Landscape Design and Management

Conserving water in landscape design and management is really very simple. By incorporating several basic principles into the development and management of landscapes, significant amounts of water can be conserved. These principles involve adequate planning and design, soil analysis, appropriate plant selection, practical turfgrass areas, efficient irrigation, use of mulches, and appropriate maintenance (Perry 1992; DeFreitas 1993; Welsh, Welch, and Duble 1993).

Developing a landscape plan is the most important principle behind successful, water efficient landscapes. These plans should consider regional and microclimatic conditions of the site, existing vegetation and site topography, intended use of the site, and the grouping of landscape plants according to their water requirements (United States Environmental Protection Agency [USEPA] 1993). The plan should allow for landscape development to be conducted in phases that can be completed gradually over a period of months or years depending on budget, personnel, or time constraints.

Soils vary considerably both within sites and between sites (Brady 1980). Identifying where these differences in soils occur, followed by a thorough laboratory analysis of each respective soil type, provides valuable information concerning plant material selection and the need for soil amendments to enhance drainage and water infiltration and storage capacity.

It is easier to grow plants appropriate to the existing soil than it is to drastically alter the soil for the purpose of growing a specific kind of plant. If possible, plant selection should always be based on the adaptability of the plant to the proposed landscape, landscape usage, and climate (Klett and Cox 1986). Plants should always be grouped according to similar water requirements, thereby reducing the potential for under- or overwatering that occurs when plants with dissimilar water requirements are planted together. Greatest water conserving benefits will be obtained by selecting plants that require minimal supplemental watering (Klett and

Cox 1986; Perry 1992). Further grouping of plants with similar water requirements according to light and fertilizer needs, results in plantings with greatly reduced maintenance demands such as pruning, weeding, fertilizing, and pest control (Walters and Backhaus 1992). Landscape professionals, university cooperative extension offices, and local garden clubs are good resources to consult when selecting plant materials. Appendix E provides a list of regional reference materials that can also be useful for selecting plant material.

Lawnlike turf areas are generally the highest user of applied water in any landscape (Ellefson, Stephens, and Welsh 1992; USEPA 1993). For certain high use areas, such as parade grounds, golf courses, and other recreational sites, turfgrass is the best landscape plant material choice because it resists wear. However, the type of turfgrass should be selected in the same manner as other plant materials with water conservation in mind. Since many varieties of turfgrass require supplemental watering at frequencies different than other landscape plants, it should be planned in both size and location so it can be watered separately (McLean 1989; Ellefson, Stephens, and Welsh 1992).

Scheduling irrigation such that plants are deeply watered only when they require it encourages deep root growth, resulting in a more healthy and drought tolerant landscape (Kourik 1993). If an irrigation system is required, it should be well planned and adequately maintained. Significant water savings can be achieved through the installation of a well planned and properly designed irrigation system. Appendix F provides a reference list for sources of water efficient irrigation systems and designs. Regionally specific information is also available from local landscape professionals and university cooperative extension agents.

Mulches applied and maintained at appropriate depths in landscape plantings will reduce erosion, prevent weed growth, and conserve soil moisture. Mulch can also be used where conditions limit or prevent adequate plant growth, resulting in a more visually appealing landscape (Lohr 1991). Many different mulching materials are available for use and typically include wood bark, sawdust, papermill wastes, pine needles, shredded landscape clippings, and assorted gravels, stones, and plastics.

Appropriate maintenance of the water conserving landscape and supporting irrigation systems will preserve the landscape, resulting in long-term sustainability. If the above principles have been followed, significant reductions in water, pesticide, fertilizer, and labor resources needed to maintain the landscape can be realized.

Landscape Audits

Driver (1995) comments on landscape conservation. Landscape audit methodology was developed by the Irrigation Training and Research Center at California Polytechnic State University at San Luis Obispo. An audit consists of a detailed inspection of the irrigation system, plant material and soil. Catch-can tests to determine the precipitation rate of the irrigation system are performed on a representative 10 percent of the site. A computer program is then used to produce an irrigation schedule. Evapotranspiration data is supplied by the State. The State of California has a Model Landscape Ordinance. An assistance program was developed that will prove funding for purchase of matching irrigation heads, updated irrigation controllers, central irrigation controllers, anti-drain valves and automatic rain shut-off devices and other devices on a case by case basis.

Experience From the Municipal Sector

Nero and Davis present the results of a landscape water audit and improvement program in the Tampa, FL, area (1993). Twenty-five properties were evaluated (apartments, commercial properties, or educational facilities) for landscape and irrigation system. The irrigation audit considered a number of factors that affect efficiency and scheduling. The landscape evaluation looked at design, management, plant selection, maintenance characteristics, and more.

The landscape analysis followed the principles of Xeriscape, which include: (1) design, (2) plant selection and placement, (3) soil analysis, (4) appropriate use of turf, (5) irrigation efficiency, (6) mulching, and (7) maintenance.

Onsite procedures for measuring irrigation efficiency began with a review of the timer and it's capabilities. The project team then walked the site, counted sprinkler heads and recorded manufacturer and model number, determined whether sprinkler heads were properly matched, identified maintenance problems, and assessed the appropriateness of the irrigation schedule given the plant selection and design for each zone.

Irrigation audits used a series of field tests for uniformity adequacy and efficiency:

- *Distribution Uniformity (DU)*. The distribution uniformity is a measure of how evenly water is applied by the sprinklers. When a perfectly uniform application is made the DU is 100 percent. In the field a DU of 70 percent or higher is considered good. Average Tampa property is 40 percent. As DU

decreases, the potential efficiency of the system also decreases, since some of the plants and turf will receive insufficient water and others will be overwatered. Distribution uniformity is determined by use of a timed catch-can test to measure volumes. In addition, pressures and flows are taken at each rotor type sprinkler head so that discharge variations and pressure variation can be evaluated.

- *Potential Efficiency*. The potential efficiency (PE) is the amount of water that could be beneficially used by the turf to satisfy the water needs compared to the total amount of water applied. No irrigation system is completely uniform, therefore some areas of the lawn are overwatered and some are underwatered. A PE of less than 75 percent usually indicates a design or maintenance problem.
- *Deficit Fraction*. Due to irrigation system design flaws, water restrictions, cost of water, or management decisions, some areas of the soil do not receive the amount of water needed to fully replenish the turf root zone. This area is referred to as the under-irrigated area. The deficit fraction (DF) attempts to answer the question: "Is the area a little under-irrigated or severely under-irrigated?" A deficit fraction of 40 percent or lower is presently considered acceptable in turf.

They found (Nero and Davis 1993) that in nearly every case, the landscape had "outgrown," or matured, beyond the ability of the irrigation system. For example, shrubs had grown well above the risers and turf interfered with spray heads. Broken or poorly aligned sprinkler heads, as well as leaks (in distribution lines and at the spray head), were observed on every property. Impractical uses of turf, either function or location, was a persistent problem. In most cases, there were zones with mixed uses of turf and shrubbery resulting in overwatering of the nonturf plants. This was also evidenced in zones mixed with plants of varying water requirements. None of the sites had installed a rain shutoff device or soil moisture measuring device as a landscape management tool. General maintenance such as mulching, pruning, fertilization, and pest control were also insufficient at most sites.

In every case, the irrigation audit results indicated that recommendations for schedule changes could be made. On average, a 28 percent reduction resulting in $5000/year savings could be achieved. The average DU for the 17 sites audited was 38 percent. Not one site was found to be acceptably efficient at the 70 percent level. Potential efficiency was also low indicative of severe design flaws or sizable leaks. Seven of 17 sites were acceptable. Other problems with the irrigation systems included mixed sprinklers and unmatched precipitation (application) rates. Shrubs and turf should be on separate zones.

Among the study's conclusions were:

- The greatest potential for water conservation, with the lowest associated cost was to change the irrigation schedule.
- Management and maintenance staff were often amazed at what was discovered, leading to greater likelihood for change.
- Financial incentives alone did not motivate property managers to incorporate changes. The budgeting process should be part of the solution to get appropriate funding.

Suggestions from a developer (Gilcrest 1993) for communities are: replace extensive areas of turf grass with inexpensive recreational amenities such as play and volleyball areas; eliminate turf from areas too steep (4:1 slope) and too small (less than 10 ft) for efficient irrigation and replace with tree and shrub plantings; use turf for greatest aesthetic and functional benefit; design irrigation systems to conserve water by completely isolating turf from planting areas with separate valves and controllers; and use drip irrigation in all planting beds.

Seacat and Waterfall (1993) reviewed landscape water conservation programs in the Tucson area. They believe large landscape irrigation consumers: parks, golf courses, schools and cemeteries should get training to key turf facility professionals to conduct their own water audits to efficiently manage landscape use. Organizational structure, lack of adequate funding for landscape maintenance equipment and personnel, and lack of established maintenance and design standards were among the impediments to achieve increased water efficiency. Despite large new investments in playing fields and renovations, no process was available for construction surveillance and no system performance standards were implemented, resulting in substandard and unmanageable irrigation systems. This resulted in a committee being formed to address key issues:

- lack of design standards for irrigation and landscape installations
- outdated material standards
- lack of a process to insure that irrigation systems be installed according to design.

Their results were production of a new Manual of Standards and Procedures containing landscape and irrigation design and installation guidelines and an inspector's checklist for plan review and field inspection. Other elements include a distributional uniformity standard (DU) of 0.65 for all new systems before acceptance.

Another goal was to use deficit irrigation and ET-based irrigation scheduling with appropriate equipment repair, retrofit and replacement. Changing out heads was a substantial task.

Other suggestions are:

- installation of landscape meters at the site to monitor water use
- upgrade irrigation equipment to raise distributional uniformities
- implementation of weather-based irrigation schedule updated monthly
- increase certain cultural practices including fertilization, aeration, and weed control.

They also conclude that the nature of water conservation requires not just technological changes, but upgraded irrigation management skills to achieve results. Cooperation with turf managers is essential for success. Savings in water use are difficult to predict because management plays such an important role.

Bennett (1993) presents the results of a survey comparing daily water consumption of single-family detached residential homes with front-yard traditional turf-oriented landscapes. The study was conducted in the East Bay region of San Francisco Bay, CA. Results yielded a 42.2 percent (209 gal/day) water savings for homes using water conserving landscapes.

To be classified as a water conserving landscape the following criteria must be met:

- The percentage of turf to total yard area must be less than or equal to 15 percent.
- The water conserving area must be composed of well-maintained vegetation.

To be classified as a traditional landscape the following criteria were required to be met:

- The percentage of turf to total yard area must be equal to or exceed 70 percent.
- The turf must be well-maintained.

He also indicated that, while in-ground sprinklers have a better uniformity of coverage than hose-end sprinklers, hose sprinklers used less water. He believes that irrigation scheduling is a critical factor, and that water efficiencies could be improved by one-third through proper scheduling.

Kiefer and DeWitt (1995) present some general findings from a study in Phoenix of watering requirements. According to the study, the likelihood of over-irrigating increases with: mean annual water use, assessed lot value, presence of a swimming pool, the use of an automatic timer, the use of an in-ground irrigation system, and the use of an irrigation guide. Over-irrigating decreases with the presence of an evaporative cooler, the use of drip irrigation, the use of a sprinkler on a hose, and the use of hand watering.

Chaumont and Gregg describe projects in the Austin area in city-wide efforts to reduce water through more efficient measures in landscape irrigation. Research projects found substantially less water (43 percent) used than traditional landscapes on lots less than 9000 sq ft. Another study found a 20 percent reduction in total water use (30 percent in outdoor use) and that landscapes with irrigation systems use about 20 percent more water than landscapes without irrigation systems.

Strategies for Conserving Water in Landscape Design and Management

A wide variety of strategies are available for conserving water in landscape design and management. These strategies are highly dependent on soil types, climate, geology, and landscape size, type, and intended use. No one strategy is going to save all of the water necessary in all circumstances for any given landscape. Therefore, landscape managers need to be aware that they have a full range of water conservation strategies that can be combined depending on factors unique to specific types or parts of landscapes.

All landscape water conservation strategies can be categorized depending on whether they: (1) preserve water that falls on the site and use it to sustain or enhance the landscape development, (2) modify the landscape development to reduce the need for water, or (3) use existing water more precisely, carefully and efficiently (Robinette 1984). In the remaining sections of this chapter, the following landscape water conservation strategies will be discussed in greater detail:

- soil improvement
- control of water falling on the site for more efficient and effective use
- selection of drought resistant plant materials and grouping according to water requirements
- leaving plant materials in a water stressed condition
- planting wind barriers
- redesign or renovation of landscapes
- altering cultural practices

- expanding the use of mulches
- using anti-transpirants
- reusing water
- establishing water priorities.

Altering or adjusting irrigation equipment and practices. Although these are not the only strategies that can be employed, they are simple, cost effective approaches that can be used by landscape managers, homeowners, and landscape designers to conserve water and ameliorate the effects of periodic drought and water shortages.

Soil Improvement

A healthy, viable soil forms the foundation for successful plant growth. It is a medium that contains a great deal of life and is important in making nutrients and water available to plants. It is not simply an inert substance that is filled indiscriminately with water and fertilizer to be absorbed by plants. Therefore, it is desirable to nurture and manage the soil with the view that it is the most important component of any landscape.

Ideal soils for conserving and releasing water most efficiently are loamy textured with high amounts of organic matter and minerals that promote plant growth, retain water, and help plants withstand drought conditions (Brady 1980). Unfortunately, most soils are not considered ideal and will benefit greatly from an ongoing, long-term soil improvement program.

Soil improvement programs are usually directed at improving the soil's physical structure or altering its soil chemistry. Initiation of these programs should always be based on soil test recommendations. Physical changes include loosening compacted soil, creating structure in structureless soils, and eliminating drainage problems. Changes of this type allow water, nutrients, and oxygen to be retained and more evenly distributed throughout the soil, resulting in greater plant availability (Ellefson, Stephens, and Welsh 1992). Compacted, clayey soils generally have extremely high runoff rates and limited water availability to plants because water infiltrates so slowly. These soil types can benefit from additions of sand, manure, compost, straw, wood chips, or other agricultural by-products that serve to improve water infiltration rates and loosen soil structure (Walters and Backhaus 1992). On the other hand, loose, sandy soils lack structure and are low in organic matter, which results in very high water infiltration rates but low retention and plant availability. Periodic additions of organic matter can significantly improve

loosely structured sandy soils by decreasing infiltration rates and improving water and nutrient retention capacities (DeFreitas 1993).

Chemical changes that may be needed include the addition of minerals and nutrients, alteration of soil pH, or reduction in soil salinity. These changes, based on soil test recommendations, are generally made to favor the growth and survival of desired landscape plantings. Providing plants with adequate nutrients and an acceptable pH encourages the healthy shoot and root growth necessary to resist pests and water stress.

Improving existing soils or replacing problem soils is a very effective long-term strategy for conserving water (Robinette 1984). It is not, however, practical for very large landscapes. Instead, soil improvement efforts should be concentrated on areas of the landscape with the greatest perceived importance and/or the greatest potential for benefit (Robinette 1984; Walters and Backhaus 1992; Ellefson, Stephens, and Welsh 1992).

Control of Water Falling on the Site for More Efficient and Effective Use

Obviously, the best source of water for landscaped areas is that which falls onto the site as rain or snow. In the past, landscapes were designed to promote fast drainage to provide a dry, usable site as soon after a rain as possible. Water that flows off the landscaped area is, however, essentially lost and may need to be replaced at some point during the growing season at considerable expense. Therefore, water conserving landscape designs should strive to use all of the water falling on a specific site without letting any of it escape. One method for accomplishing this involves slowing down falling water so that it has an opportunity to infiltrate into the soil. Adequate vegetation cover, in conjunction with well structured soils, plays an important role in controlling runoff and encouraging infiltration (Vallentine 1989). It does this by: (1) protecting the soil surface from the impact of falling rain, (2) maintaining the capacity of the soil to absorb water, (3) slowing runoff velocity, and (4) preventing channelization of runoff.

A second method for controlling falling water involves focusing the flow of falling water toward selected areas of the landscape (Robinette 1984). Most landscapes have paved areas within or adjacent to them that can be designed or renovated to direct falling water towards plantings or storage facilities instead of offsite. Curbing can also be designed to enable runoff water to be directed toward landscape areas rather than offsite. On dry, sloping, or otherwise difficult sites, water collecting saucers can be constructed around individual trees, shrubs, or entire plantings to

focus the flow of water directly toward plants rather than letting it runoff (DeFreitas 1993). These simple design tools effectively increase the amount of water available to support plant growth for an entire growing season.

Another useful method for controlling falling water involves moving water to where it is wanted or needed. Walkways, driveways, and parking areas should be designed and graded to move water to areas of the landscape where it can be used immediately or stored for later use. Grading to hold rather than to dispose of water should be a landscape design goal. Retention basins resulting from these design considerations should be lined with clay, plastic, or other impervious materials to prevent stored water from percolating through the bottom.

Selection of Drought Resistant Plant Materials and Grouping According to Water Requirements

Using drought resistant plant materials that are adapted to the soils and climatic conditions of any given landscape area would effectively eliminate the need for additional water or irrigation (Klett and Cox 1986; McLean 1989; Ellefson, Stephens, and Welsh 1992; Perry 1992; Fee 1993). Newly planned and designed landscapes should exploit this concept to the greatest extent possible. Older, more well established landscapes can also exploit this concept by evaluating existing plant materials and replacing those requiring extensive supplemental watering with more drought resistant types. Appendix E provides a list of regional references to aid in the selection of these types of plant materials. Local landscape professionals and nurseries can also provide valuable assistance in selecting appropriate drought resistant plant materials based on landscape use, erosion control, fire retardance, or other factors.

Redesigning or renovating older landscapes to improve water conservation may also require an evaluation of plant material grouping. For irrigation or supplemental watering to be efficient and effective, it is necessary to have plants with similar water requirements grouped in close proximity to one another. Plant materials with dissimilar water requirements, such as willows and cacti for example, should not be grouped together because in meeting the requirements for willows, water is wasted on cacti and may even disrupt their growth cycle or predispose them to pests and disease (Robinette 1984; Ellefson, Stephens, and Welsh 1992; Perry 1992; Defreitas 1993; USEPA 1993).

Note that most drought resistant plant materials will require water shortly after planting and during establishment (Klett and Cox 1986; Perry 1992; Walters and

Backhaus 1992; Defreitas 1993). Some drought resistant plant materials will also require occasional deep watering to encourage deep rooting. Following establishment, however, the extensive use of drought resistant plant materials will usually preclude the use of other landscape water conservation strategies. Because of this, the use of drought resistant plant materials should be one of the first landscape water conservation strategies attempted where water shortages are a concern. By using appropriate plant material selection and creative grouping, landscapes as diverse as residential areas, parade grounds, and cantonment areas can be designed or renovated to be water conserving, aesthetically pleasing, ecologically sustainable, and economically appealing (Lohr 1991; Fee 1993).

Leaving Plant Materials in a Water Stressed Condition

This strategy involves watering the plant materials just enough to keep them alive while not promoting growth. Use of this strategy should be reserved for extreme conditions and only as a short term solution. Implementing this strategy requires some knowledge concerning water requirements, growth characteristics, and water stress symptoms of the landscape plant materials (Robinette 1984; Ellefson, Stephens, and Welsh 1992). Ascertaining allowable stress levels for each plant or plant material type is often difficult and may require consultation with local agricultural extension personnel to determine when water application is absolutely necessary. The strategy works best in more informal, natural settings using plant materials that are appropriately grouped and adapted to the climate and soils of the region. For maximum benefit and applicability, it should be used in conjunction with other landscape water conservation practices such as mulching, pruning, soil improvement, and fertilizer curtailment.

Planting Wind Barriers

This strategy is based on the concept that wind barriers promote landscape water conservation by reducing wind speed, which subsequently reduces the amount of water lost to evapotranspiration. Reductions are proportional to the density and height of the wind barrier. Therefore, the area of greatest reduction will occur very close to the leeward side of dense barriers and progressively farther away from the leeward side of more porous wind barriers (Robinette 1984). If the wind barrier also provides shade, additional water can be conserved through reductions in soil temperature. Wind barriers can also act as living snow fences in colder climates, thereby accumulating additional soil water for plant growth on the leeward side of the barrier.

Wind barriers are most effective where wind velocities are relatively high and constant. Planting wind barriers helps conserve soil moisture, but they also require moisture for growth and may need supplemental water during drought to survive and retain function as a barrier. Maximum wind barrier benefits can only be obtained through careful planning that addresses orientation, prevailing wind direction, height at maturity, density, porosity, and relationship to other elements of the landscape (Robinette 1984).

Redesign or Renovation of Landscapes

In the interest of conserving water, some landscapes may require redesign or renovation. Although redesigning or renovating a landscape to conserve water may be an expensive and drastic approach, it is probably justified over extended periods of time in terms of reduced water use and landscape maintenance. Redesigning or renovating landscapes commonly involves replacing existing plants with more drought resistant plant materials and increasing the use of mulch. Some selective thinning and regrouping of existing plants according to similar water requirements may also accompany this effort. Additionally, the conversion of formal planting areas to more natural appearing areas using native, drought resistant species should be considered (Robinette 1984; Perry 1992; DeFreitas 1993). Conversion of poorly performing turf or ground cover plantings to decorative mulching is another option for conserving water in landscape redesign or renovation.

Replacing and/or installing more efficient irrigation systems is another aspect to be considered when planning for landscape redesign or renovation. Newer, more efficient systems can conserve significant amounts of water because individual stations can be programmed to compensate for differences in soil types (sandy vs. clay), exposure (sun vs. shade), plant type (turf vs. shrub), plant water requirements (drought resistant vs. water-loving), and water sources (stored vs. fresh vs. effluent) that may be encountered across any given landscape. Irrigation efficiency can be further increased by leveling mounds and redesigning other topographic features that are difficult and/or inefficient to irrigate (Robinette 1984; Walters and Backhaus 1992). Appendix F provides a list of references pertaining to irrigation systems and their design considerations.

Altering Cultural Practices

Substantial amounts of water can be conserved or more efficiently used, especially during drought conditions, through the alteration of landscape cultural practices.

These practices should be directed towards ensuring that plant materials are capable of enduring long periods of water stress, providing conditions conducive for maximum infiltration of rainfall, and enhancing the potential for deeper root growth to exploit soil water contained at greater depths in the soil profile (Ellefson, Stephens, and Welsh 1992).

In addition to using drought resistant plant materials, there are several other cultural practices that can be used to ensure that plant materials are capable of enduring long periods of water stress. Nitrogen fertilization encourages shoot and leaf growth, both of which require additional water to proceed. Under drought conditions, this additional growth is undesirable and nitrogen fertilization should be discontinued. If water is not available, nitrogen fertilization has the potential to burn and kill water stressed plant materials, necessitating expensive replacement or landscape redesign at a later date (Ellefson, Stephens, and Welsh 1992). Herbicide applications to water stressed plant materials are often ineffective or extremely toxic to physiologically compromised plants and should also be avoided (Vallentine 1989; Bovey 1977). Despite the inconsistencies and problems associated with using herbicides during periods of water stress, weed control is still very important in helping desirable landscape plant materials cope with the effects of drought. Weeds use water that would otherwise be available for landscape plant materials and through their control, water use efficiency is improved.

Under severe drought conditions, consider heavy pruning of trees and shrubs to reduce the amount of leaf area available for evapotranspirational losses of water (Ellefson, Stephens, and Welsh 1992). As soil water decreases, the ability of plant roots to meet the water needs of the entire plant also decreases. Heavy pruning reduces the amount of plant material the roots must provide water for, thereby enabling the plant to survive drought conditions for a longer period of time. For turf species, it is important to raise mowing heights and decrease mowing frequencies under drought conditions (Ellefson, Stephens, and Welsh 1992; DeFreitas 1993). Increased mowing heights provide more soil surface shading, which reduces soil temperatures and evaporative losses. Root growth and resultant water use from deeper soil depths is also promoted by increased mowing heights.

Increasing cultivation practices that core, pit, or slice fine textured and compacted soils have the potential to increase infiltration of rainfall into these soil types. These practices should be implemented before the beginning of the rainy season so that rainfall infiltration is maximized. If done during periods of extended drought, these practices expose roots to even greater drying conditions, further exaggerating water stress.

Root health and continued growth are important mechanisms in helping plant materials cope with extended dry periods. Root feeding pests can be particularly damaging to plants experiencing water stress. Diagnosis and control are critical since plant survival depends on healthy and continued root growth. Root growth into deeper soil depths is stimulated by phosphorus and potassium fertilization (Jackson and Caldwell 1989; Jackson, Manwaring, and Caldwell 1990). Providing adequate amounts of these fertilizer elements enhances the potential for continued root growth and water extraction from deeper in the soil profile.

Expanding the Use of Mulches

Mulches are essentially blankets of organic or inorganic materials that are placed over the soil and/or around plant materials to reduce soil temperatures, evaporative losses, erosion, and compaction. Mulches also limit reflectivity, reduce landscape maintenance requirements, control weed growth and competition for water, improve soil physical and chemical characteristics, and improve water infiltration (Ellefson, Stephens, and Welsh 1992). Ideal mulches should also be inexpensive and locally available in large quantities. About 75 percent of rain falling on bare soil is lost to evaporation and runoff. Two to 3 in. of mulch placed around plants can reduce both by 90 percent.

Organic mulches come from plant and animal sources such as waste material, trimmings, or decaying leaves, whereas inorganic mulches are man-made or created from inorganic natural sources. Organic mulches are part of the life-death-decay cycle and will eventually break down, necessitating periodic replenishment to retain water conserving benefits. With respect to water conservation in landscape design and management, discussion of application depths and advantages and disadvantages of various organic and inorganic mulching materials follows.

Organic Mulches

- **Shredded Bark**, 3 to 4 in. deep.
  Advantages: Long lasting material that provides good water infiltration, weed control, and soil water retention. Improves soil structure and reduces soil erosion.
  Disadvantages: Expensive and prone to compaction over time. Unattractive and ineffective if applied too thinly.

- **Wood Chips**, 3 to 4 in. deep.
  Advantages: Relatively inexpensive and provides good water infiltration, weed control, soil water retention, and soil temperature reductions. Improves soil structure and reduces soil erosion.
  Disadvantages: Decomposes in as little as 2 years, depending on material size. Smaller sized materials decompose quickly, consuming large quantities of soil nitrogen that must be replaced to assure plant availability.

- **Chunked Bark**, 4 to 6 in. deep.
  Advantages: Long lasting material that provides good water infiltration and weed control. Very attractive material for high visibility areas.
  Disadvantages: Expensive and prone to movement by wind or water unless secured with netting. Very little soil improving benefits due to size and slow decomposition rates. Not always readily available.

- **Chipper Debris**, 3 to 4 in. deep.
  Advantages: Very inexpensive mixture of tree trimming debris that provides good water infiltration, weed control, soil water retention, and soil improving properties.
  Disadvantages: Uneven, rough appearance. Decomposes relatively fast, depleting soil nitrogen, which requires replacement to assure plant availability.

- **Pine Needles**, 2 to 3 in. deep.
  Advantages: Inexpensive, attractive material that provides good water infiltration, weed control, and soil improving properties.
  Disadvantages: Limited availability and tendency to settle and form water repellent mat. Quickly decomposing material that increases soil acidity.

- **Lawn Clippings**, 1 in. layers applied as needed.
  Advantages: Inexpensive, readily available material that provides good water infiltration, weed control, soil water retention, and soil improving properties.
  Disadvantages: Must dry material thoroughly before application to prevent slimy appearance and offensive odors. May contain weed seeds and decomposes quickly, resulting in soil nitrogen depletion that must be corrected to assure plant availability.

- **Peat Moss**, 1 to 3 in. deep.
  Advantages: Good soil improving material that greatly increases water holding capacity of most soils. Provides good water infiltration and weed control as well as a slowly available source of plant nutrients.

  Disadvantages: Expensive material with limited availability that is prone to movement by wind and water, especially on slopes. Decomposes rapidly and is impervious to water when completely dry.

- **Straw**, 4 to 6 in. deep.
  Advantages: Inexpensive, readily available material that decomposes slowly and provides good water infiltration, soil temperature reduction, and soil improving properties.
  Disadvantages: Unattractive material with a tendency for wind and water movement. Will mat with time and harbors insects, disease, rodents, and weed seeds. Some fire danger when dry. Decomposition depletes soil nitrogen, which must be replaced to assure plant availability.

- **Leaves/Leaf Mold**, 2 to 4 in. deep.
  Advantages: Inexpensive, readily available material with good water infiltration, soil water retention, and soil improving properties.
  Disadvantages: Will mat with time, which may increase runoff of water. Harbors insects, disease, rodents, and weed seeds. Decomposition depletes soil nitrogen, which must be replaced to assure plant availability.

- **Compost**, 2 to 4 in. deep.
  Advantages: Inexpensive, readily available material that provides excellent water infiltration, soil water retention, and soil improving properties.
  Disadvantages: Producing compost is a time consuming process that must be conducted near the application site to avoid excessive cost. It is bulky and unsightly during processing and storage.

- **Newspaper**, 1 in. or less.
  Advantages: Inexpensive, readily available, and easily applied material that provides reasonable soil water retention and soil erosion control. Good for small areas requiring temporary mulching.
  Disadvantages: Unsightly, decomposes rapidly, and will blow away if not covered with a thin layer of soil or sand. Very low water infiltration. Not applicable for large areas.

Inorganic Mulches

- **Plastic films**, 1/8 to 3/8 in. thick.

  Advantages: Excellent soil water retention and weed control. Easy to transport and apply.
  Disadvantages: Unsightly and prone to movement unless covered with thin layer of soil. Increases soil temperatures, which may injure plant roots. Labor intensive installation.

- **Gravel, crushed stone, and river rock**, 1 to 3 in. deep.
  Advantages: Good water infiltration and soil water retention properties. Does not decompose and is available in a variety of colors.
  Disadvantages: Expensive and lacks good weed control properties unless combined with plastic films. Does not improve soil physical or chemical properties.

Polyacrylamides are chemical compounds used commonly in baby diapers to absorb urine. When added to soil, these granular materials greatly increase water retention. When the soil-polymer mixture is watered, individual polymers absorb water and swell up to 100 times their original size. Then, over the next few days or weeks, the water is slowly released into the soil where it is absorbed by vegetation. Water use can be reduced 75 percent. This technique is appropriate for golf courses, yards, schools and individuals may find it useful for potted plants.

Using Anti-Transpirants

Through normal growth and development, all plants remove water from the soil and transpire it through their leaves back into the atmosphere. In very dry conditions, transpirational losses increase and the onset of severe water stress can occur rapidly. Applying petroleum or paraffin based anti-transpirant materials to plant leaves is a means to reduce this water loss and slow the onset of water stress and its damaging effects. These materials are not a substitute for watering and do not perform well on young, rapidly growing plants or plants that have already wilted. Limited research concerning anti-transpirant efficacy indicates that transpiration can be reduced by 40 to 80 percent depending on species and application rate (Robinette 1984). This benefit, however, is limited to 7 to 14 days without repeated applications. Anti-transpirants are expensive and labor intensive to apply, which limits their applicability to rare, critical, or unusual landscape plants during periods

of extreme drought. Because of this, all anti-transpirants should be applied cautiously and evaluated on a site and species specific basis.

Reusing Water

Most of the water applied to landscapes has been treated and is fit for drinking. This represents a significant waste of water resources and other alternatives should be investigated. One suitable alternative is the use or reuse of water that has already been used for some other nonsewage purpose such as bathing, dishwashing, or laundry.

Developing large-scale recovery and delivery systems for reusing water is, unfortunately, a very expensive proposition that has many sanitary, environmental, and legal constraints. Maximizing the reuse of water with respect to these constraints requires following several principles that govern its best use. Wastewater should be applied directly rather than sprinkled onto landscape soil surfaces. Limit applications to relatively flat, well drained, and uncompacted soils where runoff is not a problem. Avoid concentrating repeated applications on small sites or landscape plantings with acid loving plant materials as sodium toxicity and soil pH increases can occur. If possible, use alternating applications of fresh and wastewater to prevent these types of potential problems. Limit applications to older, more well established landscape plantings as young plants and seedlings are susceptible to high soil pH and other impurities. Use thick mulches on areas receiving wastewater applications to facilitate decomposition of any undesirable residues contained in the wastewater.

Reusing wastewater for landscape irrigation may not be practical or appropriate in all situations, but it does have the potential to conserve fresh, potable water for other more important uses. This strategy allows irrigation water to be provided at a lower cost than fully treated water and has the added advantage of using landscape areas as natural water filtration systems (Sarsfield 1979). As wastewater percolates through the soil, many contaminants are removed, altered, or decomposed by plant roots, soil microorganisms, and soil colloids, thereby providing a natural filtering mechanism.

Establishing Water Priorities

Planning for water conservation in landscape design and management requires that priorities addressing the irrigation of plant materials with limited water resources

be established before the onset of drought or shortage. These priorities should specifically consider what plant materials get watered, how they get watered, and when they get watered. The purpose is to provide adequate amounts of water to root zones around the base of each specific type of plant material. Establishing these priorities should be based on soil types, plant types, rooting depths, ages, growth cycles, water requirements, and replacement costs (Ellefson, Stephens, and Welsh 1992; Walters and Backhaus 1992; DeFreitas 1993). Accessibility and/or adaptability of existing irrigation systems will also be important factors in developing priorities. Landscape areas with high visibility and heavy usage patterns are additional factors to consider when establishing water priorities. Many of the previously discussed strategies for conserving water in landscape design and management, such as soil improvement, selection and appropriate grouping of drought resistant plant materials, leaving plants in a stressed condition, alteration of cultural practices, expanded use of mulches, and reuse of wastewater make it much easier to establish water priorities.

Altering or Adjusting Irrigation Equipment and Practices

Water conserving landscapes require minimal amounts of supplemental irrigation to maintain plant materials. When irrigation is required, it should be applied in an effective and efficient manner making every drop count. Irrigation systems should be designed and zoned so that plant materials grouped according to similar water requirements are watered separately from those with different water requirements (Smith 1986; Kourik 1993). This requires the selection of irrigation systems or methods appropriate for each plant material type within the landscape. Irrigation systems can be designed to conserve water by completely isolating turf from planting areas with separate valves and controllers. Use drip irrigation in planting beds.

Drought resistant trees, shrubs, and many ground covers planted in low water use areas will require supplemental water only during their establishment, while other less drought resistant plant materials may need irrigation during periods of water shortage when they exhibit signs of stress. Simple, temporary systems such as soaker hoses or hand watering may suffice under these circumstances. Harsher site conditions, coupled with frequent periods of water shortage, may necessitate the installation of a permanent drip irrigation system to maintain trees, shrubs, and ground covers. Conversely, some plant materials, such as turfgrasses or ornamentals, may require a more expensive, permanent irrigation system with automatic controls. Appendix F provides a list of valuable references concerning the design, selection, and maintenance of irrigation systems and components for specific landscape elements. Landscape professionals, university extension personnel, and

local garden clubs can also provide information concerning the design, installation, and maintenance requirements of efficient and economical irrigation systems suitable to a given geographic region.

Sprinkler irrigation can be as simple as a single nozzle or oscillating device attached to a garden hose or as complex as a series of underground pipes, pop-up sprinkler heads, and automatic controls. Generally, turfed areas less than 2000 sq ft in size can be efficiently and economically irrigated using portable equipment consisting of hoses and simple nozzles or oscillating sprinklers (Ellefson, Stephens, and Welsh 1992). Automated sprinkler irrigation systems with pop-up heads are preferred for uniformly irrigating much larger turfed areas, such as athletic fields, parade grounds, and golf courses, where it would be difficult and extremely time consuming to manually water using portable equipment. For other types of landscape plantings, such as ornamental flower beds, trees, shrubs, and vegetable or fruit gardens, drip irrigation or soaker hoses are probably a better choice.

Lawn watering is often the largest water consuming activity for a single use in a residential setting, not to mention the large acreage present as parade grounds, athletic fields, parks, golf courses, etc. Sprinklers that shoot water into the air can waste 50 percent on a hot and dry day, especially on windy days. Soaker hoses, which deliver water directly to the root zone, are best for lawns and can reduce water loss by 50 percent or more. Grass type also impacts and determines water demand. Zoysia, Bermuda and St. Augustine grasses require the least watering.

Efficient and economical automated sprinkler irrigation systems with multiple supply pipes and individual controls can be installed for around $0.56/sq ft of turfed area (Means 1994). All automated sprinkler irrigation systems begin with good design that addresses location and spacing of sprinkler heads to avoid wasting water through excessive spray overlap and watering of nonvegetated surfaces (Smith 1986; Watkins 1987). Properly located and spaced sprinkler heads conserve water provided that application rates are uniform and do not exceed the intake capacity of the soil. This is achieved by selecting pipe sizes based on desired flow rates through the pipe (Watkins 1987). If pipes are too small, excessive water pressure losses occur causing some sprinklers to apply more water than others (Smith 1986). Periodic monitoring of application rates, followed by proper maintenance and/or adjustment, assures effective, efficient, and economical sprinkler system operation. The irrigation system should have a timer or moisture sensors to activate the system and watering should be done before sunrise or after sunset to reduce evaporation losses. Turfed areas and planters, trees and shrubs may be watered separately to meet differing needs. Proper system maintenance is essential to irrigation water conservation. Sprinkler heads should be inspected regularly. Damaged, worn, or

broken heads should be replaced promptly. Sprinkler heads should be cleaned periodically to remove mineral deposits and maintain efficiency. The system should be inspected for leaks in pipes, couplings, and hose bibs and repaired as necessary. Sprinkler timing cycles should be adjusted monthly to meet varying seasonal demands. Appropriate plant selection and placement reduces water usage. Low and high water use plants should not be mixed; this will help avoid unnecessary watering of the low water use plants. Higher water use plants can be planted in low areas that intercept runoff, thereby decreasing the need for supplemental watering. Regular maintenance of turf and gardens conserves irrigation water. Turf should be cut to the proper height: 1-1/2 to 2 in. for cool season grasses, and 3/4 to 1 in. for warm season grasses. Dethatching and aerating turf increases aeration and infiltration, which leads to healthier turf and decreased water consumption. Drought resistance is assisted by decreasing nitrogen fertilizers and increasing potassium levels. Weeds will compete with desired plants for water and should be removed regularly.

Automation

Irrigation timers and moisture sensors can also be used to save water. Timers that regulate irrigation systems can be set to water at times of least evaporation. Many people forget to adjust their timers if rain is predicted, or if it has already rained and there is no need to water. The solution to this problem is to use a moisture sensor. This device will activate the irrigation system only when the lawn requires water. If it has rained, the system will not turn. Unnecessary watering also can occur if rain is predicted after the lawn was watered. When anticipating rain, the device would have to be turned off before it activated irrigation. Outdoor water saving devices are grouped in two categories: rain collection devices and soil sensors. Rain collection devices are generally simpler, less expensive, and more reliable when compared to soil sensors. Most of the devices feature a pan for rain collection. When the pan fills to a certain level, the irrigation system is turned off. When evaporation reduces the water in the pan beneath that level, the irrigation system is re-enabled.

Another type of irrigation water-saving device is the soil sensor. This type of device features either one or two probes that measure the moisture in a certain depth of soil, usually toward the top and bottom of the root zone. As the soil becomes drier, the sensor triggers the irrigation system to begin watering for a specified period. If the soil is still dry after a short waiting period, another irrigation cycle will begin. The two main disadvantages are the cost of the system and the difficulty to install it. Prices vary from $100 to $621.

Drip irrigation, also known as trickle or micro-irrigation, applies water slowly and directly to plant root zones through small flexible pipes and flow control devices called emitters (Smith 1986; Wade et al. 1992; Kourik 1993). This also minimizes evaporation. Drip irrigation systems use about 30 to 50 percent less water than sprinkler systems and are also about 50 percent less costly to install (Kourik 1993). They do, however, have higher maintenance requirements and costs than sprinkler irrigation systems. For greatest efficiency, keep drip systems as simple as possible and use them on less drought resistant trees, shrubs, and flowers within the landscape (Smith 1986). There are many types of drip irrigation systems that can be adapted to a variety of applications, from watering individual trees and shrubs to larger plantings of annuals, herbaceous perennials, or ground covers.

Ferguson (1993) discusses application of subsurface irrigation to playing fields. Subsurface drip irrigation (SSDI) is the slow, controlled delivery of water (and nutrients) to the root zone of plants. This can often result in a savings of 50 percent or more in water use. Traditional drip irrigation lines are aboveground. However, for playing fields, this is clearly impractical, requiring burial. One-half-in. driplines are installed about a foot underground and spaced according to the soil and plant characteristics. Water moves by capillarity through the soil, providing a moist layer under the plants' root zone resulting in an appropriate system for sports' turf.

SSDI is efficient and can yield savings of 15 to 75 percent in water compared to sprinklers. It can deliver water and nutrients directly to the root zone at the appropriate time if connected with one of the new sensor-controlled systems. Ferguson goes on to describe the advantages as: (1) the system is invisible, (2) it is vandal proof, (3) it eliminates injuries due to protruding sprinkler heads, (4) the system can last for 20 years, (5) it reduces compaction and diseases, (6) it allows irrigation to be done during daytime use, and (7) it allows great possibilities for use of reclaimed water.

A major problem has been the clogging of emitters by roots. A solution has been the incorporation of Treflan (an herbicide) into emitters during the manufacturing process.

Ferguson (1993) suggests a design similar to other drip systems with a few precautions. Emitter-lines should be buried below aeration depth (8 to 12 in. below grade. Spacing is determined by the soil's holding capacity ranging from 12 to 24 in. Other components include: fertilizer injector (optional), filters, pressure or flow regulator, electric solenoid valves, irrigation controller, vacuum relief vent, and emitter lines. A flushing line should also be included.

Operation and maintenance should be done to maintain moisture at the root level of the plants without oversaturating as turfgrass needs both air and water. Watering will require a few minutes daily or every second or third day. The amount of water applied is proportional to the time the system is running. Evapotranspiration rates are used as a guideline with the following equation:

$$A = \frac{38.5 \times Q}{(Sr \times Sd)/144} \qquad \text{[Eq 3]}$$

Where:

A (in./acre)	=	application of water per 24-hour day
Q (gal/hour)	=	emitter discharge rate
Sr (in.)	=	spacing between drip rows
Sd (in.)	=	spacing between emitters.

The filter must be checked regularly and the lines flushed out at the ends.

Ferguson (1993) describes costs for material for a 5-acre sports field as 15 to 20 cents per sq ft with method of installation a primary factor in cost. Large open areas allow tractors to plow 3 or 4 emitter lines underground in one pass significantly reducing costs with sprinkler systems that require trenching, piping, backfilling and recompaction. She also suggests reduction of perceived health risks with reclaimed water compare with surface application.

In water conserving landscapes, minimizing supplemental water applications is a primary goal. When required, there are several practical guidelines for using supplemental water more efficiently. Time of water application affects efficiency, and when using sprinkler irrigation, the best time is between 2100 and 0900 hours (Turner and Anderson 1980). Between these hours, reduced wind velocities and lower temperatures reduce evaporative losses. Conversely, during the hottest part of the day, the sun can evaporate as much as 50 percent of the water sprayed by sprinklers before it has a chance to infiltrate into the soil (Ellefson, Stephens, and Welsh 1992). Drip irrigation is not prone to substantial evaporative losses and can be conducted any time of the day.

For most landscape plantings, infrequent deep irrigations are preferable to frequent shallow irrigations, which do not encourage the downward root growth necessary to exploit soil water located deeper in the soil profile (Ellefson, Stephens, and Welsh 1992; DeFreitas 1993; Kourik 1993). The majority of tree and shrub roots capable of absorbing water are located near the plants drip line. Irrigation, whether by hand, portable sprinkler, or drip system, is therefore most effective if concentrated at or near the drip lines of trees and shrubs.

Allowing irrigation water to pond and subsequently runoff a landscape is one of the biggest wastes of supplemental water, especially during periods of extreme water shortage. Application of irrigation water should not be allowed to exceed the soils potential to absorb it. As a general rule, 1 in. of supplemental water is enough to penetrate the soil to a depth of 12 in. for sand and 6 in. for clay (Brady 1980). Sandy soils are capable of absorbing water at a rate of about 0.5 to 0.75 in. per hour, whereas clay soils are only able to absorb about 0.1 to 0.25 in./hour (Hanks and Ashcroft 1986). Typical sprinkler heads can deliver somewhere between 0.5 and 2.0 in. per hour (Wade et al. 1992). Therefore, water application rates should be adjusted according to soil type to avoid ponding and runoff. For heavy clay soils, this may require irrigating in 15 to 30 minute cycles or until runoff begins, allowing for infiltration, and repeating the cycle until 1 in. has been applied. For turfgrasses, ground covers, and flower beds, 1 in. of water should be applied at each irrigation event to encourage downward root growth. Heavier water applications are necessary for most shrubs and trees because their root systems penetrate deeper into the soil profile. Portable soaker hoses and drip irrigation systems are ideal for this purpose.

Summary

Well planned and designed landscaping has the potential to conserve significant amounts of water. By using available water more efficiently, designing or redesigning landscapes that require less water, and applying supplemental water more effectively and precisely, landscape water use can be reduced by 30 to 80 percent. Strategies for conserving water in landscape design and management involve: (1) improving the ability of soils to collect and retain water, (2) controlling water falling on the site for more efficient and effective use, (3) selecting plant materials that require less water and grouping them together according to water requirements, (4) leaving plants in a water stressed condition and only watering when stress symptoms suggest impending death, (5) planting wind barriers to reduce evaporative and transpirational water losses, (6) altering cultivation, mowing, pruning, and fertilization practices, (7) expanding the use of mulching materials to reduce weed growth, soil temperatures, evaporative losses, erosion, and compaction, (8) using anti-transpirants to reduce water loss from plant tissues, (9) reusing wastewater to irrigate plant materials instead of treated, potable water, (10) establishing water priorities addressing when, where, and what landscape plant materials should receive supplemental water in the event of drought or water shortage, and (11) altering or adjusting irrigation equipment and practices to assure that supplemental water, when necessary, is applied as efficiently, effectively, and economically as possible.

16 Water Audits

Blease (1993) discusses institutional, commercial, and industrial water audits. A water audit is an essential first step towards the achievement of water reduction at nonresidential facilities. The audit identifies and quantifies the areas of water use in a systematic and methodical manner so that a real understanding is gained of the wide variety of areas of water consumption. The full range of options for water reduction are analyzed and a water efficiency program developed. The potential areas for water reduction are prioritized to maximize savings. Furthermore, the involvement of the facility staff in the audit process helps to develop commitment and secure sustainable water conservation. The recommendations for water reduction will be, in the main, for changes of fittings or process. However, it is also important to create a "water wise" environment to encourage water user habit change.

To enhance the understanding of the water audit procedure, the key tasks are reviewed. It is important to emphasize that the water audit is a team effort that combines the experience and skills of the auditing team with the facility staff's knowledge of their own building.

To begin with, a start-up meeting takes place with the auditing team and the facility operating staff to explain the audit purpose and procedures and to outline the support required from the building operators. This meeting marks the beginning of the team effort. Historical water consumption for the previous 3 years is analyzed to confirm how representative the study period is. This is necessary to ensure that an assessment of year-round savings can be made. Site plans and plumbing drawings are reviewed.

The areas of water use in the facility are next identified and a schematic drawing prepared showing the general area of use. To quantify the volumes of water used, the facility's flowmeters are read during the monitoring period. Additional sub-meters are installed where this is considered necessary. While the main flows into the site are being monitored, the individual volumes of use are estimated from a combination of field measurements, equipment references, discussions with local staff and recent actual experience. Next, a water balance is completed, based on the categories of water use. The three main categories of water use are domestic,

cooling, and process. Within these main categories, the individual areas of use are identified, along with their period of use during the day and associated estimated volume. The method of discharge, to the sanitary or storm sewer, or to evaporation, is also indicated.

From the foundation of the work completed to this stage, the potential water reduction options are identified. Realistic and practical options for water conservation are evaluated. Any water conservation measures already implemented are taken into account. A simple cost/benefit analysis is performed to demonstrate the potential savings, modification costs, and payback periods. The recommendations for water reduction will mainly be for changes of fittings or process, or reduction in cooling water. These changes are selected following the evaluation of alternatives. However, it is also important to create a "water wise" environment to encourage water user habit change and also ensure that any water reductions achieved are maintained in the future.

More detailed procedures and information can be found in the AWWA Publication "Water Audits and Leak Detection" and the Military Handbook on Water Conservation.

17 Data Analysis

Kiefer (1993) presents information addressing a complex issue. Just how one evaluates the effectiveness of plumbing retrofit programs. Developing evaluative information can be costly when a comprehensive analysis is desired. Estimates of water savings from conservation devices have varied tremendously. A fundamental reason for abandoning mechanical estimates was based on the premise that mechanical estimates did not take into account the confounding factors that affect the rate and level of total household water use (i.e., weather, household size, price, ongoing conservation activities, and others). Researchers have therefore produced widely divergent estimates of plumbing retrofit savings. When such savings estimates are used in financial and management decisions, close inspection of researchers' assumptions and measurement methods is critically important. He examines three separate techniques:

1. Comparison of means (i.e., pre-post tests)
2. Time-series regression of aggregate data
3. Multiple regression of household-level data.

Comparison of means (i.e., pre-post tests) essentially compare average annual household water use in the entire single-family sector (or other defined population) before and after implementation of plumbing retrofit. This method assumes that any significant difference in average water use after implementation of a conservation program, is indeed a result of treatment (i.e., caused by household installation of retrofit devices). However, this process mistakenly attributes external effects to the retrofit program such as droughts, increased rainfall, mandatory use restrictions, etc. and will provide inaccurate values.

In a time-series regression specification, water savings from a plumbing retrofit is estimated by the coefficient of a binary (0/1) variable that assumes a value of "1" only in months following the introduction of a retrofit program. Savings estimates exceeded maximum theoretical estimates. These findings implied that the time-series modeling approach, together with the binary specification of the retrofit variable, tends to produce overstated water estimates of water savings, i.e., unreliable estimates.

A more refined way to develop estimates of water savings is to use multiple regression of household-level data including household observations on water use, and socioeconomic and conservation variables that are postulated to affect household water use. This information would then be combined with time-series data on household water use and weather to form pooled databases for multiple regression analyses.

Kiefer's (1993) recommendations include:

- Avoid the comparison of means approach because it cannot isolate effects of a retrofit from other confounding influences and results in biased and overstated estimates of water savings.
- Time-series regression should be discouraged because it relies on aggregated average data. It is also difficult to obtain corresponding time-dependent observations on important explanatory variables. The regression equations then may lack the ability to differentiate between factors that are really affecting household water use.
- The best and preferred method is to use household-level survey and water use data in conjunction with multiple regression techniques. The survey instrument should be designed for precise definition/distinction of the groups of households to be evaluated. Great care must be taken in choosing appropriate treatment and control groups.
- Finally, mechanical or engineering estimates should be used as a benchmark to evaluate validity of findings.

A useful primer and information source for more detailed procedures and analyses can be found in "Evaluating Urban Water Conservation Programs" (O'Grady et al. 1994).

18 Relevant Ongoing Programs

Federal Demonstration

A Federal building demonstration of water efficient equipment has been installed in Denver, CO, to showcase potential savings and advantages. A typical office building had ultra-low flush wall-hung flushometer valve toilet, a waterless urinal, a sensored lavatory system, and a computer-controlled irrigation system (Mayo 1995).

Information Sources

Many utilities have begun to undertake conservation programs for business/ industrial water users. A valuable resource for those wishing to research the activities of other programs is the InCon.Net database, which presents information regarding people and programs in the specialized field of industrial-commercial-institutional water conservation. InCon.Net was developed by and copies are available from Jane Ploeser of the City of Phoenix Water Services Department (tel.: 602 262-8366). It is also available on AWWA's AWWANET computerized bulletin board service.

There is substantial information available through the American Water Works Association Water Wiser (A Water Efficiency Clearinghouse) network, telephone: 1-800-559-9855. The mailing address is: AWWA, 6666 West Quincy Avenue, Denver, CO 80235-9913. The website for Water Wiser is www.waterwiser.org.

Arizona, California, Colorado, Oklahoma, Texas, and Utah have all established specific offices of water conservation. Many States also have technical assistance, public information materials, school materials, and water conservation is often a topic of State-sponsored research.

Partnerships

Jones and Dyer (1993) discuss a partnership between the Federal government and utilities. The Federal government strives to simultaneously cut costs and improve environmental quality. Similarly, utilities want to improve profits and expand supplies by selling less water and energy.

One group has designed a solution: retrofit Federal facilities with efficient technologies and finance the improvements through existing utility contracts with the government. The Federal installations (and therefore taxpayers) will pay lower bills, the utilities supply water and energy at the least cost, the environment enjoys more water in rivers and less pollution in the air and entrepreneurs thrive through social responsibility. The partnership is expecting to get profits and savings from the wasteful technologies in Federal buildings. Pilot audits show promise. By integrating a water retrofit and an energy retrofit, the contracted professionals will consider retrofitting technologies such as chillers, cooling towers, lighting, toilets, faucets, flush valves, landscaping, ice machines, and heating systems. They will also consider leak detection and repair and water reuse.

Projected benefits include:

- no initial capital investment of government funds, and guaranteed lower utility bills
- projected 20 to 35 percent reduction in water and energy use
- creation of construction jobs in high unemployment areas with no increase to Federal agency budgets
- improved worker comfort, greater productivity, and lower absenteeism
- reduction in air emissions from electrical production.

This partnership features creative use of existing contracts. Instead of recreating utility/government contracts, a process that would have taken several years and required Congressional approval, the partners slashed layers of bureaucracy and added a simple line item on the existing utility bill for the repayment of all project capital. Energy Saving Performance Contracts (ESPCs) are awarded through Huntsville Division of the Corps of Engineers. *However,* there is a potential problem with partnerships and performance contracts in determining baseline water usage, and attributing water savings to conservation measures (as opposed to personnel reductions, changes in weather conditions, etc.).

19 Summary

U.S. military installations have a number of options to choose from to respond to the water conservation mandates of the Energy Policy Act and Executive Order 12902:

1. *Water Conservation.* A program to conserve water might either encourage more efficient water use, or reduce demand for water resources. Water Integrated Resource Planning (IRP) is an inclusive variety of techniques to help planners determine the appropriate mix of resources to meet consumer water needs (Chapters 2, 4).

2. *Retrofit and New Plumbing Fixtures.* Often, retrofit or replacement of common water fixtures (toilets, urinals, faucets, showerheads, drinking fountains, etc.) can conserve water and pay back the cost of the improvement within 1 year (Chapter 5).

3. *Water Distribution System Maintenance.* Water suppliers can take actions to save water by detecting and reducing leaks, installing water meters, and addressing unaccounted for water (Chapter 6).

4. *Institutional, Commercial, and Industrial Water Use.* Nonresidential (business and industrial) water use differs from residential water use in that conservation measures must account for a more diverse set of water uses, and because these measures must be incorporated into institutional business practices (Chapter 7).

5. *Implement Conservation Measures in Cooling and Heating Systems.* The choice of heating and cooling systems appropriate to local climate can reduce these systems' water demands (Chapter 8).

6. *Implement Conservation Measures in Hospitals and Health Care Facilities.* Hospitals and health care facilities use large volumes of water due to their requirements for clean and sterile environments, and due the fact that they often incorporate various water-using systems into a single facility: kitchen,

cafeteria, laundry, heating and cooling, sterilizing facilities, landscaping, etc. (Chapter 9).

7. *Implement Conservation Measures in Kitchens, Mess Halls, and Cafeterias.* Activities such as dishwashing, garbage disposal, ice making, food preparation, sanitation, and cleanup use large quantities of water, and offer opportunities for more efficient water use (Chapter 10).

8. *Implement Conservation Measures in Laundries.* Both choice of equipment and optimal use of laundry equipment can offer substantial water savings (Chapter 12).

9. *Implement Water Harvesting.* Under certain circumstances, stormwater runoff can be captured stored for later use, offering substantial water savings (Chapter 13).

10. *Reuse "Greywater."* Greywater, or untreated household wastewater that has not come into contact with toilet waste, can (in some locations) be reused for landscape watering (Chapter 14).

11. *Make Water-Efficient Use of Irrigation and Landscaping.* Sensible landscape design, coupled with appropriately programmed irrigation, can help maintain landscaped environments while minimizing water loss from landscape watering (Chapter 15).

12. *Perform Water Audits.* A water audit, which identifies and quantifies areas of water use in a systematic and methodical way, is an essential first step to achieve a reduction in water use in nonresidential facilities (Chapter 16).

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Appendix A: Water Integrated Resource Planning

There is no concise definition of the term "Integrated Resource Planning" (IRP). By its very nature, a planning process as complex and diverse as IRP does not lend itself to definitions that are brief and, at the same time, useful. The best way to understand the meaning and value of IRP is to step through the process. While there are wrong ways to implement IRP, there is no single "right" approach. There are as many variations of IRP as there are practitioners. The details of the IRP process differ depending on the particulars of the situation to which IRP is being applied. Planners and managers must always make tradeoffs between the benefits and costs of increasing degrees of comprehensiveness of a planning effort. The decision must be made locally and will differ among agencies.

How is IRP different from "traditional" planning? This question does not have a simple answer. IRP is not totally distinct from what many agencies are already doing. It is equally inaccurate to label it the "same old thing." It includes many components that characterize a well-performed traditional planning effort. However, it also includes pieces (e.g., extensive analysis of conservation programs, careful consideration of uncertainty, and coordinated efforts to involve and inform the public) that are not generally found in traditional water supply planning. IRP also reflects a philosophy that eschews rules of thumb and recognizes the value in making explicit the elements that underlie most planning — namely, that decisions must strike a balance between often-conflicting objectives.

The final product of an integrated resource planning process will be one or a few "resource strategies." A resource strategy specifies a particular mix of supply-side and conservation resources. For each such resource, the strategy must indicate at what future point and under what future conditions the resource should be added. The description of a resource strategy must also include the interactions among the component resources, and the performance of the strategy relative to the agency's planning objectives.

To produce this product in a rigorous and defensible fashion, a sequence of planning steps is required. The process is typically nonlinear, there are many links among

IRP components, and it is often necessary and desirable to perform multiple iterations of one or more steps. Briefly, the steps are:

1. *Define planning objectives and associated evaluation criteria.* This critical step must go well beyond a broad statement of planning goals. It must be the result of an introspective process to determine what is really important to the agency, followed by the development of measurable criteria against which to evaluate alternative resource futures.
2. *Involve the appropriate constituencies.* Involving and informing political leaders, key stakeholders, and the public at large is a hallmark of IRP. The breadth and magnitude of such involvement will vary widely depending on the needs of the local area and the perceived level of interest in the resource alternatives that are being considered.
3. *Assess supply options.* Potential supply options must be identified and then evaluated in a rigorous, multi-tiered fashion. The purpose of this component of the IRP process is to narrow the range of alternatives to be considered in developing integrated resource strategies and to clearly specify the important characteristics of each such alternative so that the resource plan can be evaluated.
4. *Assess conservation options.* This step is the demand-side counterpart of the previous one. While specific tools may differ, the rigor and structure of the analysis must be similar to allow the different types of resources to be jointly considered and successfully integrated. The conservation options considered may include various pricing alternatives and water reuse.
5. *Formulate and evaluate resource strategies.* Resource alternatives that emerge from the foregoing assessments must be intelligently combined. These resource combinations must then be subjected to multi-tiered evaluation against agreed-upon evaluation criteria until a small number of resource strategies emerge. These strategies should span the range of policy alternatives facing decisionmakers and explicitly illustrate the tradeoffs among the different evaluation criteria.

Appendix B: Greywater Guide

Using Graywater in Your Home Landscape

Graywater Guide

Pete Wilson
Governor
State of California

Douglas P. Wheeler
Secretary for Resources
The Resources Agency

David N. Kennedy
Director
Department of Water Resources

December 1994

Graywater is untreated household waste water which has not come into contact with toilet waste.

Includes: used water from bathtubs, showers, bathroom wash basins, and water from clothes washing machines and laundry tubs.

Does not include: waste water from kitchen sinks, dishwashers, or laundry water from soiled diapers.

(from California Graywater Standards)

Thanks to the Urban Water Research Association of Australia for their contribution of four illustrations from their publication, *Domestic Greywater Reuse: Overseas Practice and its Applicability to Australia.*

Foreword

California's Graywater Standards are now part of the State Plumbing Code, making it legal to use graywater everywhere in California. These standards were developed and adopted in response to Assembly Bill 3518, the Graywater Systems for Single Family Residences Act of 1992.

This Guide was prepared to help homeowners and landscape and plumbing contractors understand the Graywater Standards and to help them design, install and maintain graywater systems.

Carlos Madrid
Chief, Division of Local Assistance

Table Of Contents

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Why Use Graywater?

Are you tired of watching your bathing and laundry water go down the drain when it could be put to good use on your landscape? Now it is safe and legal to reuse that "graywater" and this guide shows you how.

In addition to conserving water and probably reducing your water and sewer bills, you will also be "drought-proofing" your landscape by using graywater. Since more than half of your indoor water can be reused as graywater, during shortages, when outdoor watering may be restricted, you will have a constant source of water. With landscapes valued at between 5 percent and 10 percent of the value of a home, this back-up supply of water may be an important economic insurance policy for you. Furthermore, the nutrients in graywater may be beneficial to your plants.

The seven steps to follow to put graywater to use in your landscape are:

1. Investigate the permit process
2. Prepare a plan
3. Design the graywater system
4. Submit the plan for review and approval
5. Install the system
6. Arrange for system inspection and approval
7. Use, monitor and maintain the system

If you decide not to do some of the steps yourself, you can hire a landscape contractor to install the irrigation system or a plumbing contractor to install the plumbing. They will follow this same process.

To better illustrate how to install a residential graywater system, this guide features the Brown family. In examples throughout the text, this family of four follows the seven steps.

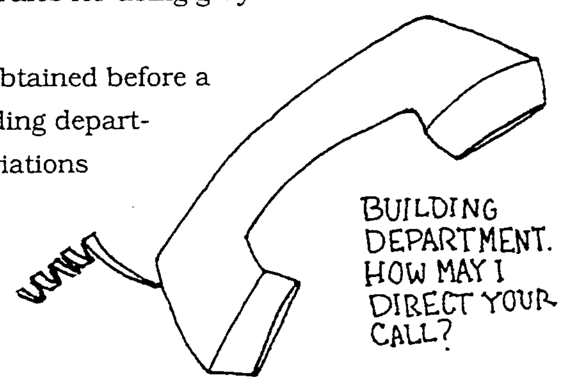
The Seven Steps

The following seven steps will help you plan, design, install, and maintain your graywater system.

1. Investigate the Permit Process

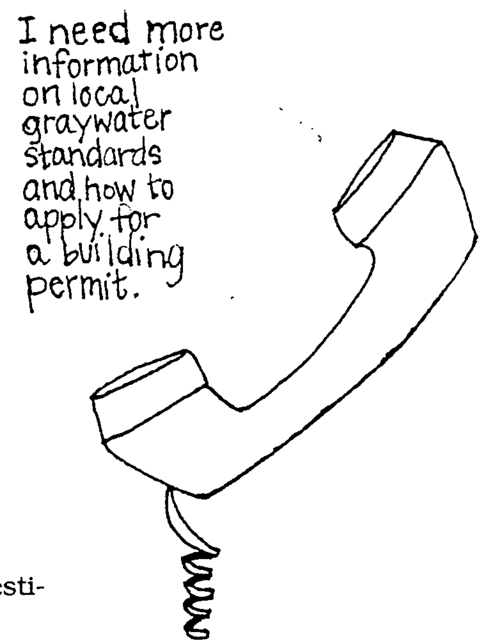
Information in this guide is based on the California Graywater Standards. In the appendix, you will find a copy of Title 24, Part 5, of the California Administrative Code, GRAYWATER SYSTEMS FOR SINGLE FAMILY DWELLINGS, commonly called the California Graywater Standards (Appendix J). These are the official rules for using graywater in California.

The Standards require that a building permit be obtained before a graywater system is installed. Check with your local building department for information on their permit process and any variations made to the Graywater Standards before you proceed.



2. Prepare the Plan

Is a graywater system for you? By first learning approximately how much graywater your family will produce and how much landscape you can irrigate with it, you will be better able to decide. Determining whether your soil is suitable for a graywater system is another primary consideration. Once you have decided that a graywater system is in your future, the next step is to draw a plan and design your system.



Estimate the Amount of Graywater Your Family Will Produce

The number of plumbing fixtures which you connect to the graywater system will determine how much graywater is available for irrigation use. See the section entitled "Plumbing System: Pipes and Valves" page 8 for more information about accessing plumbing fixtures.

The Graywater Standards use the following procedure to estimate your daily graywater flow:

(1) Calculate the number of occupants of your home as follows:

First Bedroom	2 occupants
Each additional bedroom	1 occupant

(2) Estimated daily graywater flows for each occupant are:

Showers, bathtubs and wash basins (total)	25 Gal./Day/Occupant
Clothes washer	15 Gal./Day/Occupant

(3) Multiply the number of occupants by the estimated graywater flow.

Example: The Brown family has a three bedroom house so the system must be designed for a minimum of four people. If all fixtures are connected, then each occupant is assumed to produce 40 gallons of graywater per day, resulting in a total of 160 gallons each day.

The reason graywater flow is based upon the number of bedrooms rather than the actual number of people is that the number of bedrooms will remain constant, while the number of people may vary over time.



Estimate the Amount of Landscape You Can Irrigate

Graywater is distributed subsurface and will efficiently maintain lawns, fruit trees, flowers, shrubs and groundcovers. It can be used to irrigate all plants at your home except vegetable gardens.

You do not need to do the following calculation as part of the permit process, but it will help you determine just how much landscape your graywater will irrigate and how many plumbing fixtures you may want to hook up to the system. On page 6, you will find specific information about determining the minimum required irrigated area.

You can estimate either the square footage of the landscape or the number of plants which can be irrigated. Generally, estimating the square footage is more useful for lawn areas and subsurface drip irrigation systems while estimating the number of plants would be more useful for trees and shrubs irrigated by a mini-leachfield system.

Use this formula to estimate the square footage of the landscape to be irrigated:

$$LA = \frac{GW}{ET \times PF \times 0.62}$$

where:

LA = landscaped area (square feet)

GW = estimated graywater produced (gallons per week)

ET = evapotranspiration* (inches per week)

PF = plant factor

0.62 = conversion factor (from inches of ET to gallons per week)

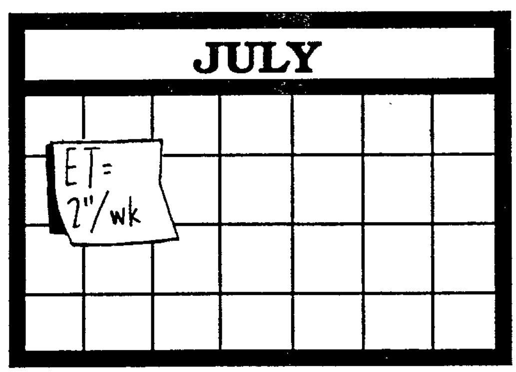
*Evapotranspiration is the amount of water lost through evaporation (E) from the soil and transpiration (T) from the plant. (This formula does not account for irrigation efficiency. If your irrigation system does not distribute water evenly, extra water will need to be applied.)

Example: If the Brown family living in Sacramento produces 160 gallons of graywater per day, how much lawn can be irrigated with that graywater? (160 x 7 days = 1120 gallons per week)

$$LA = \frac{1120}{2 \times .8 \times 0.62}$$

LA = 1129 square feet

Since Sacramento has an ET of 2 inches per week in July (the peak irrigation month in most areas of California), the Brown family can irrigate 1129 square feet of lawn with the available graywater.



If the landscape includes less water thirsty plants, more than twice as much square footage can be irrigated. For specific information about evapotranspiration and estimating landscape water needs, see University of California Leaflet 21493, *Estimating Water Requirements of Landscape Plantings*, and *U.C. Water Use Classification of Landscape Species*. These publications can be obtained through your county cooperative extension office. Also, in the appendix, you will find a list of evapotranspiration rates for the month of July for selected sites in California.

An alternative to considering the square footage of the landscape is to estimate the number of plants that can be irrigated with this 1120 gallons of graywater per week. Here is a look-up chart to help you determine approximately how much water an individual tree or shrub will need for one week during July:

Climate	Relative Water Need of Plant (Plant Factor)	Gallons Per Week 200 SQ FT CANOPY	100 SQ FT CANOPY	50 SQ FT CANOPY
Coastal	low water using (0.3)	38	19	10
(ET=1in/wk)	medium water using (0.5)	62	31	16
	high water using (0.8)	100	50	25
Inland	low water using (0.3)	76	38	19
(ET=2in/wk)	medium water using (0.5)	124	62	31
	high water using (0.8)	200	100	50
Desert	low water using (0.3)	114	57	28
(ET=3in/wk)	medium water using (0.5)	186	93	47
	high water using (0.8)	300	150	75

[The gallons per week calculation for this chart was determined with the following formula: Gallons per week = ET x plant factor x area x .62 (conversion factor.)(This formula does not account for irrigation efficiency. If your irrigation system does not distribute water evenly, extra water will need to be applied.)]

Example: The 1120 gallons of graywater per week produced by the Brown family in Sacramento could irrigate:

8 young fruit trees:	8 x 50 = 400 gallons	(high water using, 50 foot canopy)
8 medium-sized shade trees:	8 x 62 = 496	(medium water using, 100 foot canopy)
7 large shrubs:	7 x 31 = 217	(medium water using, 50 foot canopy)
total:	1113 gallons per week	

The number of gallons of water per week a plant needs will vary from season to season, plant to plant, and site to site, but this will give you a general idea about the number of plants you can successfully irrigate in July with your graywater.

Irrigation needs of the landscape may be greater than the total available graywater. So, even if the system includes the shower, tub and clothes washer, some supplemental water would be necessary during the hot summer months. Contrarily, the amount of available graywater may be greater than the amount you can use on the landscape. In that case, you can reduce the number of plumbing fixtures connected to the graywater system.

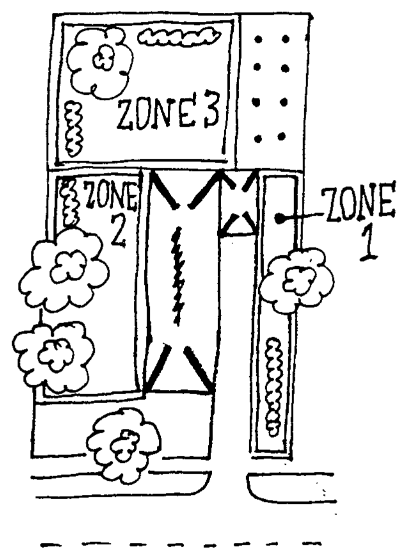
Gather Soil and Ground Water Data

Determine the soil types and ground water level on your property. The local building department will probably provide this information or allow you to use Table J-2 of the Graywater Standards. If this information is not available, consult with the local building department about the approved soil testing method. They may require that you hire a

qualified professional to conduct a percolation test, or may allow you to do it. Usually you would be required to dig test holes in close proximity to any proposed irrigation area and conduct a percolation test. The U.C. Cooperative Extension Office, the county agricultural agent or a local geologist, soil scientist or college instructor will be able to assist with soil type identification and characteristics. The United States Department of Agriculture Soil Conservation Service publishes a Soil Survey of every county which may be helpful for this purpose.

Draw a Plot Plan

A plot plan of your property should be drawn to scale and may be required to include dimensions, lot lines, direction and approximate slope of the surface. The location of retaining walls, drainage channels, water supply lines, wells, paved areas, and structures should be included. If you have a septic tank, show the location of your sewage disposal system and the required 100 percent expansion area. Provide information on the number of bedrooms and which plumbing fixtures will be connected to the proposed graywater system. Finally, indicate the landscape area that you plan to irrigate with graywater.



Determine the Size of the Irrigated Area

Above, you learned how to estimate the amount of landscape you can irrigate based on the graywater produced and the water needs of the plants. Now you need to determine the minimum size of the irrigation field required, based on soil type. With either a subsurface drip or mini-leachfield system, at least two irrigation zones are required and each must irrigate enough area to distribute all the graywater produced daily without surfacing.

For sub-surface drip irrigation systems, Table J-3 of the Graywater Standards is used to determine the number of emitters required. The emitters must be at least 14 inches apart in any direction.

Example: The Brown family produces 160 gallons of graywater per day and irrigates plants in a sandy loam soil. Based on Table J-3, the minimum number of emitters per gallons per day of graywater production is .7 x 160 = 112 emitters. With at least 14 inches between each emitter, the total irrigation area for one zone would be 112 emitters x 14 inches / 12 inches (to get square feet) = 130 square feet. The Browns would need 130 x 2 = 260 square feet for the minimum of two irrigation zones required by the Graywater Standards to safely distribute their graywater without surfacing.

As we discovered earlier, the Browns could irrigate up to 1129 square feet of lawn with 160 gallons of graywater per day. Therefore, they can design their system to irrigate over four times the minimum irrigated area in this case and still maintain a healthy landscape.

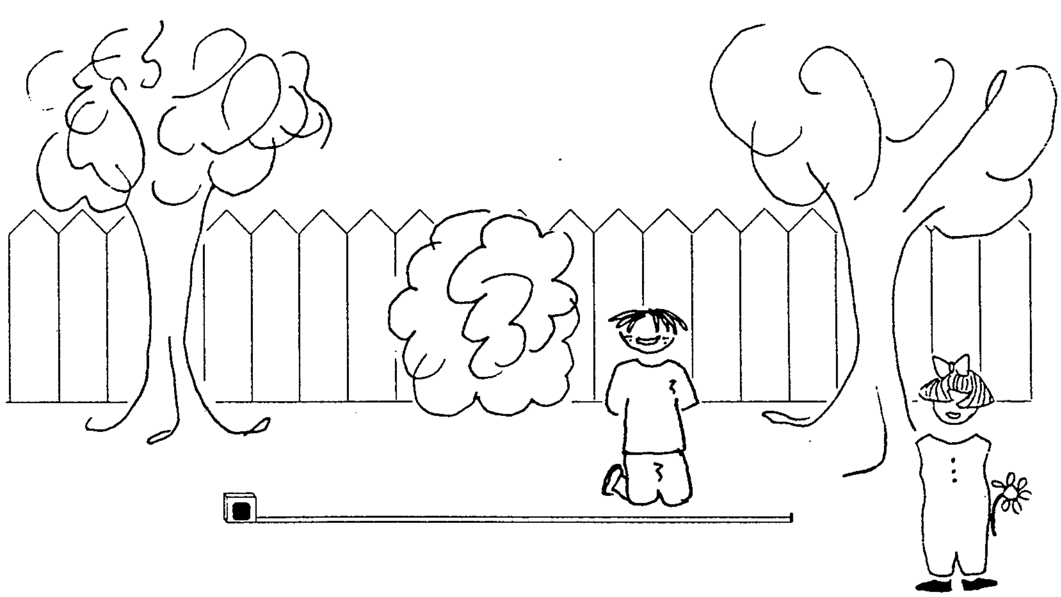
If the mini-leachfield irrigation system is used, the required square footage is determined from Table J-2 of the Graywater Standards.

Example: The Brown family produces 160 gallons of graywater per day and is irrigating a sandy loam soil. Based on Table J-2, the minimum square feet of irrigation area for a mini-leach field system would be 40 square feet per 100 gallons, (160/100=1.6)1.6 x 40 = 64 square feet. The Browns would need two irrigation zones, each 64 square feet in size, a total size of 128 square feet.

The Browns want to install a 100-foot line with a trench that is 8 inches wide to irrigate the 8 fruit trees and 7 large shrubs along the perimeter of their yard. Then, they want to install an 80 foot line with a trench that is 1 foot wide to irrigate 8 mature shade trees. To calculate the area of the mini-leachfield irrigation field, the length of the line as well as the width of the trench must be considered. Therefore, the total area of the irrigation field would be 66 square feet (100 ft. length x .66 ft. width) + 80 square feet (80 ft. length times 1 ft. width) = 146 square feet. Since 146 square feet is greater than the minimum required irrigated area for a mini-leachfield (128 square feet), and since each zone is greater than the required 64 square feet, the Browns meet the minimum irrigated area requirement.

Determine Location of the Graywater System

Once you know the size of the irrigation field, based on the soil and plant needs, you can decide where to put it. Table J-1 in the Graywater Standards establishes distances that the surge tank and irrigation field have to be from various features, such as buildings, septic tanks, and the domestic water line. In addition, your system must be designed so that no irrigation point is within five vertical feet of the highest known seasonal ground water.



3. Design the Graywater System

The next step is to determine the different components of your graywater system and prepare a description of the system itself. Included will be a determination of the irrigated area and details of the graywater system. This construction plan includes a description of the complete installation including methods and materials.

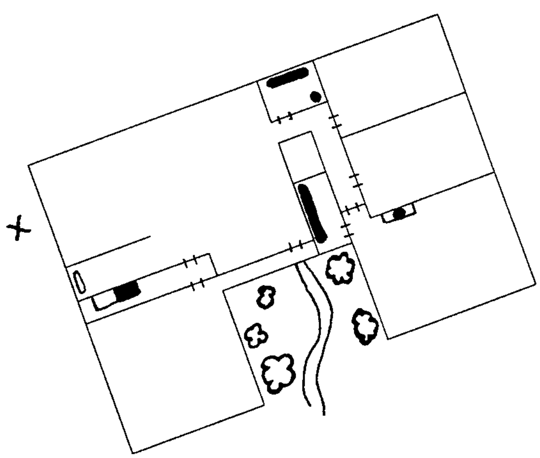
A graywater system usually consists of:

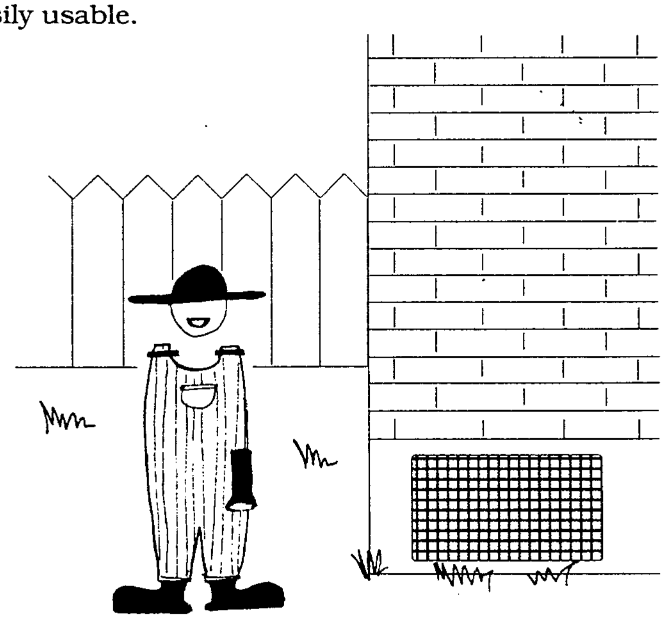
Plumbing System made up of pipes and valves to bring the graywater out of the house
Surge tank to temporarily hold large drain flows from washing machines or bathtubs
Filter to remove particles which could clog the irrigation system
Pump to move the water from the surge tank to the irrigation field
Irrigation System to move the water to the plants

It may be helpful to refer to Figure 1 in the Graywater Standards to get a sense of the overall layout of a graywater system. Then continue reading this section which describes the different parts needed to assemble your system. In your plan, all of the parts of your graywater system must be identified as to the manufacturer.

Plumbing System: Pipes and Valves

The plumbing fixtures which can be used easily in a graywater system depend on the building's foundation. If your home is built on a slab foundation, most drain pipes are buried beneath the concrete slab and the graywater from the bath and shower are unusable without expensive remodeling. However, if your washing machine is located near an outside wall or in the garage, the water is easily usable.



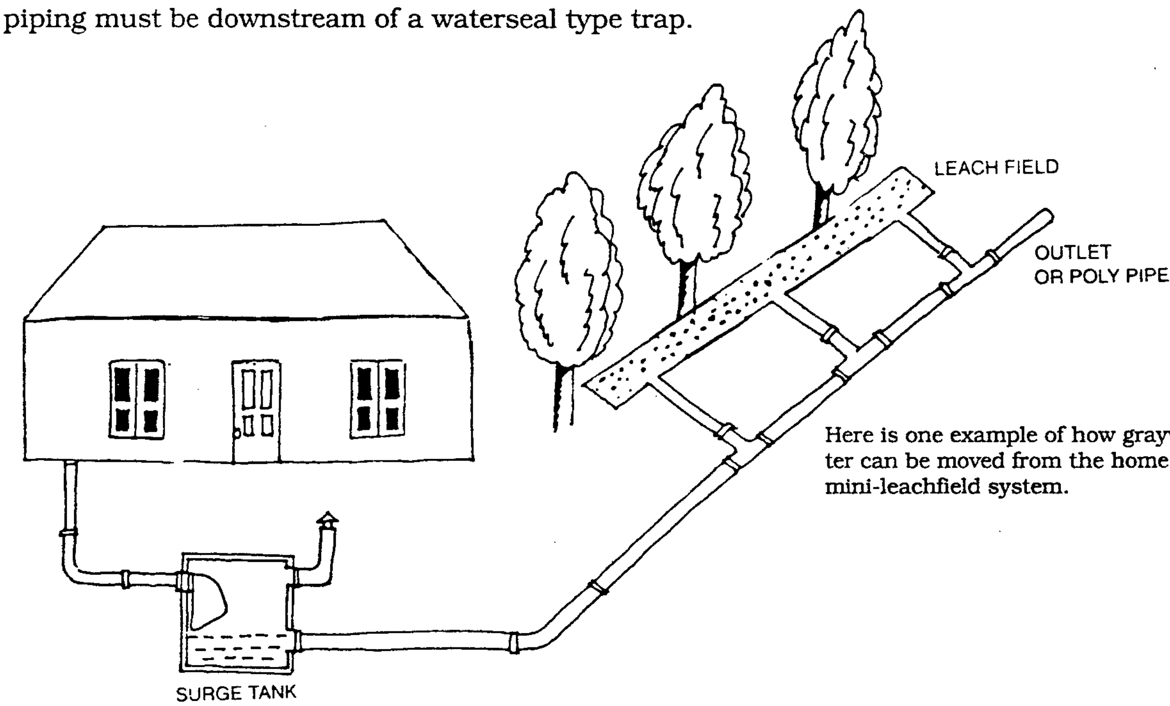


If your home is built on a raised foundation, the drain pipes are generally accessible from the crawl space. Before you enter the crawl space, draw a floor plan of your house, noting the location of the shower, bath, washing machine, and bathroom sinks. Under the house, identify which drain lines serve which fixtures and decide which ones you would like

to include in your system. The more fixtures included in the graywater collection system, the more graywater you will have, but the more plumbing changes you will have to make. If you are remodeling your home, this is a great time to access the plumbing and install a graywater system.

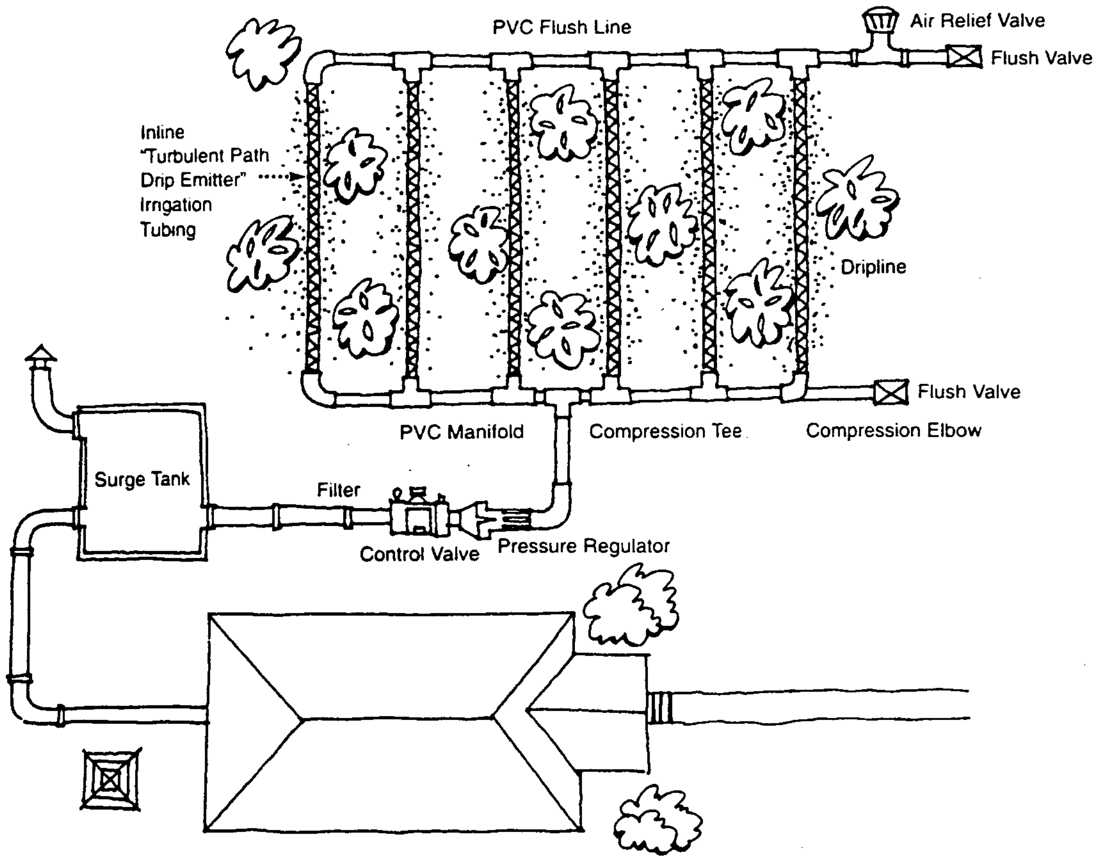
The Graywater Standards require that all graywater piping be marked "Danger-Unsafe Water." This is usually done by wrapping the pipe with purple tape, which is available at most irrigation supply stores. You can install graywater plumbing to a new house for future graywater use even though you are not quite ready to install the irrigation system. This capped off, preliminary plumbing, often referred to as "stub-out plumbing," is allowed in the Graywater Standards as long as it is properly marked.

All valves in the plumbing system must be readily accessible, and backwater valves must be installed on surge tank drain connections to sanitary drains or sewers. Finally, piping must be downstream of a waterseal type trap.



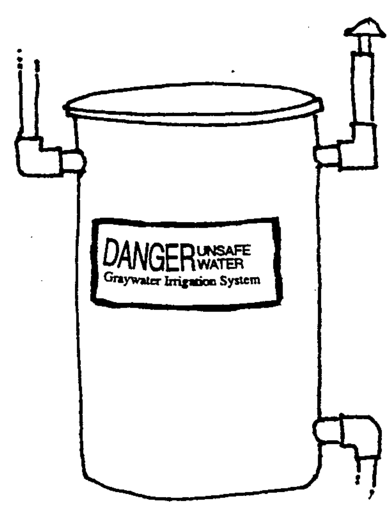
Here is one example of how graywater can be moved from the home to a mini-leachfield system.

This illustration shows a typical hook up from the home to a subsurface drip system.



Surge Tank

Where a graywater pipe exits the home's foundation, it is routed to a surge tank. The tank can be located near the house or, if the line is run underground, nearer the irrigation area. The tank must be solid, durable, watertight when filled, and protected from corrosion. The tank must be vented and have a locking gasketed lid. It must be anchored on dry, level, compacted soil or on a three-inch concrete slab. The capacity of the tank and "GRAYWATER IRRIGATION SYSTEM, DANGER- UNSAFE WATER" must be permanently marked on the tank. The tank drain and overflow gravity drain must be permanently connected to the sewer line or septic tank. The drain and overflow pipes must not be less in diameter than the inlet pipe.



Filter

For subsurface drip irrigation systems, a 140 mesh (115 micron) one inch filter with a capacity of 25 gallons per minute is required. A mesh size of 140 means that a screen has 140 openings per square inch. The size of the openings are 115 microns (a micron is equal to one-thousandth of a millimeter) each, which is equivalent in measure to a 140 mesh.

Pump

If all of the plants you wish to irrigate with graywater are below the building's drain lines, then the graywater system and irrigation lines could use gravity to distribute the water. If any of the plants you wish to irrigate with graywater are higher than the surge tank or the building's drain lines you will need a small, inexpensive pump to lift the water to the plants. A pump will increase the cost of the system slightly .

To pick the right size pump you must know:

1. the 'head' (the total lift measured in feet from the pump to the highest point in the landscape) of your system;
2. the distance from the tank to the furthest point you wish to irrigate; and
3. the maximum discharge rate of all your graywater sources.

For both distance and head, the pump's specifications must show a gallon-per-hour (gph) or gallon-per-minute (gpm) rate. Make sure that the rating is at least 10 gpm at the head you will be using. Try to get a pump that does not need water cooling so that all the water can be pumped out of the tank. Buy a pump that meets or exceeds your needs. Check the manufacturer's specifications.

Irrigation System

The Graywater Standards allow for two kinds of irrigation systems to be used for graywater: sub-surface drip irrigation or mini-leach fields.

Subsurface Drip Irrigation System

Here is a description of the various parts of a subsurface drip irrigation system:

<u>Emitters:</u> The minimum flow path of the emitters is 1200 microns (the holes can be no smaller than 1200 thousandths of a millimeter in size). The coefficient of manufacturing variation (Cv) can be no more than 7 percent. Cv is a method of describing how evenly the emitters apply water at the time they come from the factory. According to the American Society of Agricultural Engineers, good emitters have a Cv of 5 percent or less, average emitters are between 5 and 10 percent, and marginal emitters are between 10 and 15 percent. Emitters must be recommended for subsurface and graywater use and demonstrate resistance to root intrusion. (To determine the emitter ratings of various products, check with your local building department or order a copy of the Irrigation Equipment Performance Report, *Drip Emitters and Micro-Sprinklers*, from the Center For Irrigation Technology, California State University, 5730 N. Chestnut Ave., Fresno, CA 93740-0018, (209) 278-2066.)

<u>Supply lines:</u> PVC class 200 pipe or better and schedule 40 fittings must be used

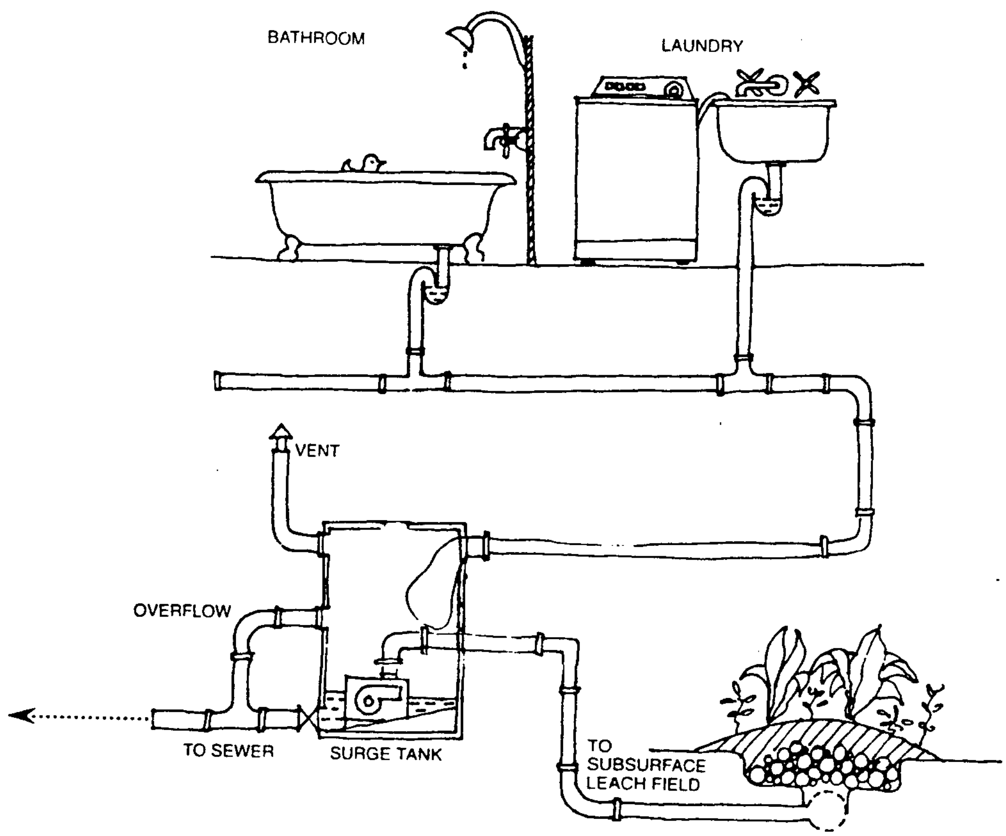
for all supply lines. Joints, when properly glued, will be inspected and pressure tested at 40 psi and must remain drip tight for 5 minutes. All supply lines must be buried at least 8 inches deep.

Drip lines: Poly or flexible PVC tubing shall be used for drip lines which must be buried at least 9 inches deep.

Pressure reducing valve: Where pressure at the discharge side of the pump exceeds 20 pounds per square inch (psi) a pressure reducing valve must be used to maintain pressure no greater than 20 psi downstream from the pump and before any emission device.

Valves, switches, timers, and other controllers: These devices are used, as appropriate, to rotate the distribution of graywater between irrigation zones and to schedule the irrigations.

Automatic flush valve/vacuum breaker: These devices are required to prevent back syphonage of water and soil.

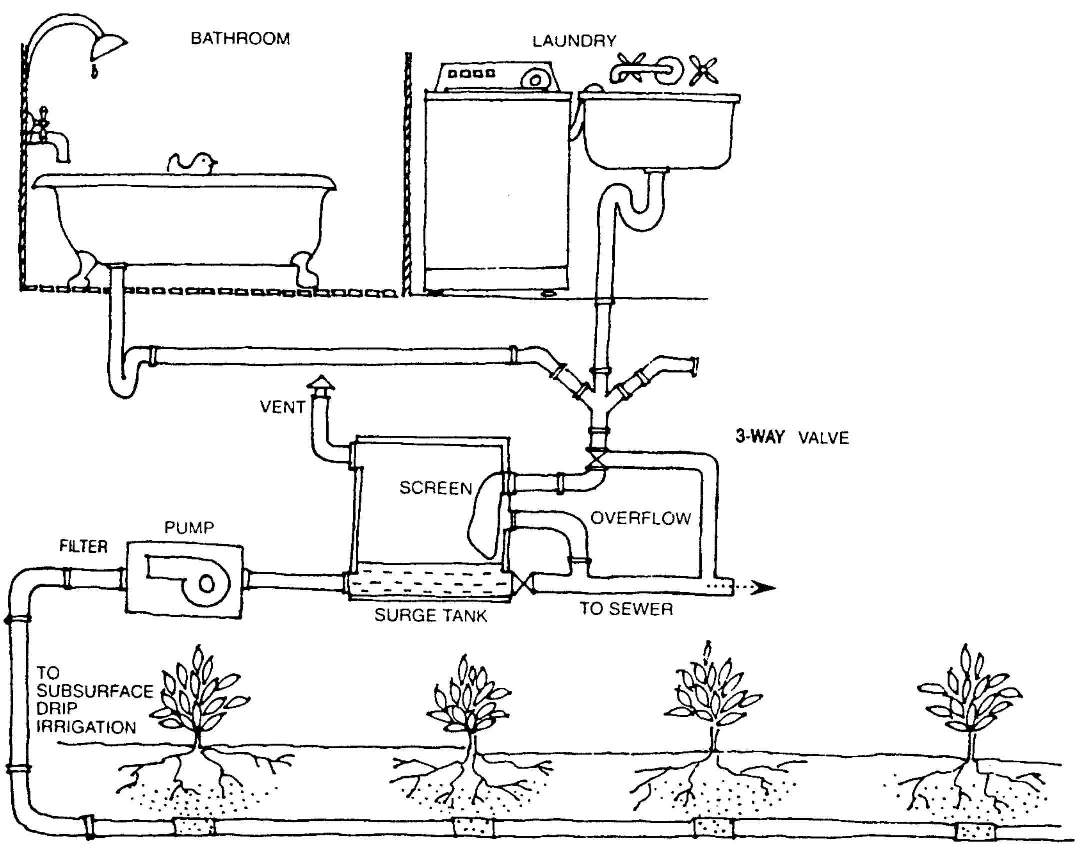


Mini-Leachfield System

The dimension specifications of the mini-leachfield are found in the Graywater Standards, Section J-11 (b) (3). Here is a description of the various parts of a mini-leachfield system:

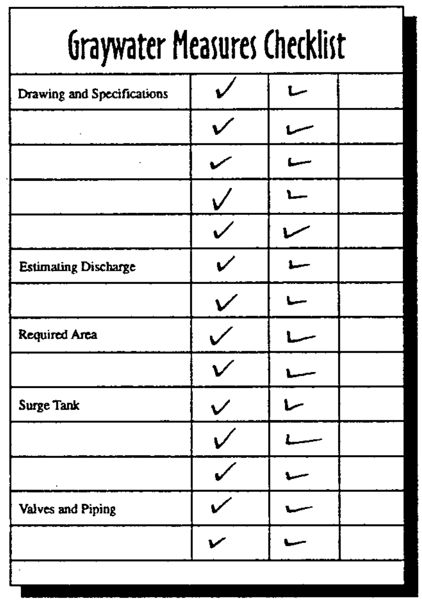
Perforated pipe: The pipes must be a minimum 3-inch diameter, constructed of perforated high density, polyethylene, ABS, or PVC pipe, or other approved material. The maximum length is 100 feet; minimum spacing between lines is 4 feet; and the maximum grade is 3 inches per 100 feet.

Filter material: A clean stone, gravel, or similar material, sized between 3/4 and 2-1/2 inches, must be used. This filter material is then covered with landscape filter fabric or similar porous material before being covered with earth. Do not backfill the trench until after it has been inspected.



4. Submit the Plan for Review and Approval

Once you have completed the application form, plot plan, construction plan, and soil and ground water determinations, submit them to the building department. Staff will review your submittal to insure that you are in compliance with the Graywater Standards. Most likely, they will have a form listing the provisions of the Graywater Standards and will check off each item as they determine it conforms with the regulations. In the Appendix you will find a sample Graywater Measures Checklist on page 31. Once your submittal is approved, you may begin installation of your graywater system. Remember that the building inspector will want to inspect your system before you cover the subsurface drip irrigation lines or backfill the mini-leachfield trenches.



5. Install the System

Purchase the Equipment

Your construction plan includes a description of the materials to be used for the graywater system. This will form the basis of your "shopping list." On the following page is a shopping list for the system the Brown Family plans to install.

In most cases, the plumbing parts, pump and tank can be purchased at your local plumbing supply store. Look in the Yellow Pages under "Plumbing Fixtures, Parts, and Supplies, Retail." The Yellow Pages also has listings for "Pumps-Dealers" and "Tanks-Fiber Glass, Plastic, Etc," or "Tanks-Metal" if your first stop does not have all the parts you need.

"Irrigation Systems and Equipment" is the heading to look under for the components of the subsurface drip irrigation system. The pipes for a mini-leachfield system can be purchased from a plumbing supply store and the gravel filter material can be found at a "Sand and Gravel" company, listed as such in the Yellow Pages.

There are some specialty sign companies that produce the warning labels such as "GRAYWATER IRRIGATION SYSTEM-DANGER-UNSAFE WATER," needed for your graywater system.

Parts and Approximate Costs for the Brown Family Graywater System*

Parts	Approximate Cost ($)	
washing machine hook-up		
connection parts	20	
three-way diverter valve	28	
pipe to sewer	4	
pipe to tank	4	
sanitary tee	3	
shower/bath hook-up		
connection parts	15	
pipe to tank	4	
bends	15	
fittings	15	
vent	13	
Total: Plumbing Parts		**$121**
55 gallon tank with lid	101	
vent	13	
inlet pipe	4	
overflow pipe	4	
drain pipe	4	
backwater valve	4	
water seal type trap	3	
emergency drain ball valve	28	
tank adapters ($20 each, one for each pipe)	60	
union	12	
Total: Tank Parts		**$233**
Total: Pump		**$150**
AND		
Subsurface Drip Irrigation System		
filter 140 mesh one-inch 25 gal/min	25	
pipe: PVC class 200	12	
fittings: schedule 40	15	
drip lines: 112 emitters	46	
valves ($25 each)	50	
automatic flush valve ($2 each)	4	
controller	50	
switches	32	
pressure reducing valve	15	
compression T's	4	
Total: Drip Parts		**$253**
OR		
Mini-leachfield		
solid pipe	50	
perforated pipe: 180 ft.	70	
gravel, 18 in /130'/1' = 7 yds.	70	
landscape filter fabric	40	
Total: Leachfield Parts		**$230**
GRAND TOTAL: DRIP		**$757**
GRAND TOTAL: LEACHFIELD		**$734**

*Cost for permit fees, rental equipment, professional installation, and maintenance not included.

Install the Plumbing System

Modifying drain lines usually requires extensive plumbing knowledge and skills; seeking professional assistance is recommended. This guide does not provide basic plumbing instructions. If you are a do-it-yourselfer, the staff at a retail plumbing store, plumbing books at the library, or friends may be able to provide you with the plumbing information you will need for most of the plumbing work associated with a graywater system.

The drain pipes in homes built before 1970 are generally cast iron, while those built since 1970 will probably be plastic. The tools required to make the necessary plumbing changes will usually include: a hacksaw, tape measure, flashlight, hammer, pipe wrenches (metal pipes only), and screw drivers. An electric drill and a hole saw may be necessary to provide access holes through walls. If you do not have the necessary tools, most rental companies rent these tools inexpensively. Be careful not to connect any part of the graywater system piping to the existing water supply system.

In order to clearly identify graywater pipes, all graywater lines must be continuously marked along the entire length of the pipe with a warning label. Identification of graywater pipes is important to avoid the possibility of cross-connecting graywater pipes with fresh water supply lines. This is for your protection as well as for the protection of future occupants of your home who may be unaware of the exact location of the graywater plumbing and is especially important with graywater pipes that resemble standard freshwater supply pipes.

Install the Subsurface Drip Irrigation System

Once again, this guide provides a brief overview of the installation process, not basic landscape irrigation instructions. You can call the local chapter of the California Landscape Contractor's Association or their state office at (916) 448-2522 for a list of qualified referrals to install subsurface drip irrigation systems.

If you decide to do it yourself, first, gather all the parts you have determined will be needed for your system. There are special tools for digging the trenches for the drip lines, or you can do it with an ordinary shovel. After the trenches are dug, it is recommended that you install the main valve, filter, and pressure regulator first. Next, install of the main PVC lines and finally the drip lines. Once the system is fully installed, test it for leaks. Don't cover the system until it is inspected and approved.

Install the Mini-Leachfield System

To create a mini-leachfield, dig a trench along the dripline (the outer edge of the foliage) and fill it with gravel to within nine inches of the surface. Be sure to cover the gravel with a landscape filter fabric or similar material before filling the trench with soil. If soil is able to infiltrate down into the gravel, the mini-leach field will quickly clog and the water will be forced to the surface.

6. System Inspection and Approval

Once all the plumbing is connected, the tank in place, and the irrigation system in the ground (but uncovered), arrange to have a building inspector come out for the final inspection and approval. The inspector will be checking that the surge tank remains water-tight as the tank is filled with water; that all the lines remain watertight during a pressure test; and that the other measures listed on the Graywater Measures Checklist in the appendix meet the Graywater Standards.

7. Using, Monitoring and Maintaining the System

Protect Health

If a member of a household is ill, graywater may carry infectious bacteria or viruses. However, in order for the graywater to make another person ill it would be necessary for that person to drink or otherwise consume the contaminated graywater. As long as a person does not drink the graywater or irrigate vegetables with graywater and then eat them unwashed, graywater is safe.

The Graywater Standards require that graywater not surface and that human contact with graywater be avoided. Graywater systems designed, installed, and maintained in accordance with the standards present minimal risk to public health. The California Department of Health Services participated actively in the development of these standards to insure the protection of public health.

When graywater is used, always follow these rules :

Don't drink or play in graywater.
Don't mix potable (drinking) water with graywater.
Don't allow anything that may be eaten to come into contact with graywater.
Don't allow graywater to pond on the surface or run off the property.

Select Garden-Friendly Soaps

The chemical and biological composition of graywater varies greatly, based on numerous factors, including the original quality of the water coming to your home, the personal habits of the family members, which plumbing fixtures are connected to the system, and the soaps used. Since the type of detergent you select is one major factor that you can control, the use of garden-friendly soaps can contribute significantly to better quality graywater.

Most hand and dish soaps and shampoos will not damage plants at low residential concentrations. Laundry detergents, on the other hand, need to be selected carefully. Sodium and boron are chemicals that can have a negative effect on landscapes. Powdered detergents and soaps include "filler" ingredients (not essential to clothes cleaning) which are usually some compound of sodium. Liquid soaps contain few fillers, thus less sodium.

A few soaps are now being formulated for use with graywater systems. Cleaners and laundry soaps you may wish to **avoid** are:

bleaches or softeners (send graywater to sewer when used)

detergents that advertise whitening, softening and enzymatic powers

detergents with ingredients which include:

boron, borax, or chlorine, or bleach

peroxygen or sodium perborate

petroleum distillate or alkylbenzene

sodium trypochlorite

Often the labeling on detergents is incomplete. The University of Arizona Office of Arid Lands Studies (with the sponsorship of Tucson Water) tested the composition of many common detergents for sodium, boron, phosphate, alkalinity, and conductivity. High alkalinity often indicates a high level of sodium. Conductivity is the measure of all dissolved salts in the water. The higher the concentration of salts and minerals, the greater the potential for adverse impacts on the soil and plants. Phosphates are good for plant growth, but the detergent form may not always be usable by the plants. The Office of Arid Lands Studies suggests that you select detergents with the lowest levels of alkalinity, conductivity, boron, and sodium. This information is included in the Appendix.

Generally, once people begin to use graywater, they think more carefully about what they put down the drain. Some cleaning products are toxic to plants, people and the environment and should not be used. Products designed to open clogged drains or clean porcelain without scrubbing **must** be sent to the sewer or replaced with alternative products or boiling water and elbow grease.

Also, home water softeners often use a solution that contains high levels of sodium chloride that may have a negative effect on soils. Avoid using softened water as graywater when possible.

Keep Soils Healthy

Sodium, potassium and calcium are alkaline chemicals. Because of the presence of these chemicals in laundry detergent, graywater use tends to raise alkalinity of the soil. Slightly alkaline soils will support many garden plants. Even most acid-soil loving plants will be happy with slightly alkaline soils that are generously amended with organic matter. The pH of an acid soil is 6.9 or lower while that of an alkaline soil is 7.1 or higher. If a simple pH test indicates that the pH reading is over 8.0, the pH should be reduced. This can be accomplished by adding agricultural sulfur or an acidifying fertilizer such as ammonium sulfate.

Problems with water infiltration may be due to a sodium build up in the soil. Soil

analyzed by a soil lab is the only way to verify excess sodium. Depending upon the severity of the problem, you can usually correct it by adding agricultural gypsum and/or organic matter to the soil.

A sandy, well-drained soil will be less affected by the application of graywater than a poorly drained clay soil. Sometimes graywater may degrade the structure of a clay soil by making it stickier and less loamy. The soil's physical condition also may be affected by high sodium. To correct these problems and keep soil healthy, once again, till in organic matter.

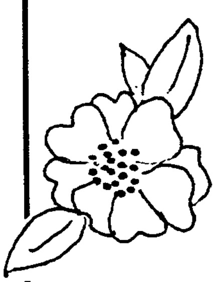
The salts that might build up from the use of graywater will only be a problem if they are not leached away periodically by heavy rains. If winter rains are light, occasionally leach the soil with fresh water.

Grow Healthy Plants

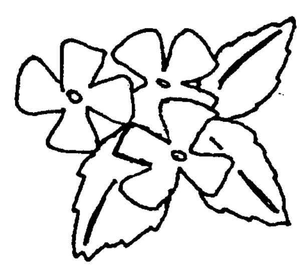
The application of too much water, of any kind, too frequently will result in saturated soils, and an invitation to plant disease. Generally, plants are healthier when the soil is allowed to dry out between irrigations.

A very small percentage of plants may be damaged by graywater, most of these are listed below. Too much sodium or chlorine could result in leaf burn, chlorosis (yellow leaves), and twig die back. Boron can be toxic to plants at levels only slightly greater than is required for good plant growth. Symptoms of boron toxicity include leaf tip and margin burn, leaf cupping, chlorosis, branch die back, premature leaf drop, and reduced growth.

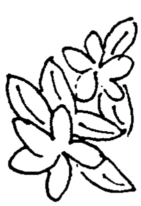
Shade loving and acid loving plants do not like graywater. Their native habitats are forested areas where acid soils predominate. Here are some plants that are not suitable for the alkaline conditions often associated with graywater irrigation:



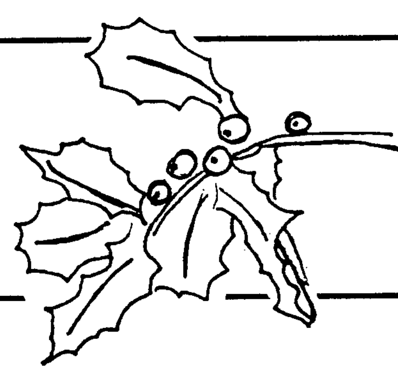
Rhododendrons
Bleeding Hearts
Oxalis (Wood Sorrel)
Hydrangeas
Azaleas
Violets
Impatiens
Begonias
Ferns
Foxgloves
Gardenias
Philodendrons
Camellias
Primroses



Other plants that are especially susceptible to high sodium, and chloride which may be present in graywater are:

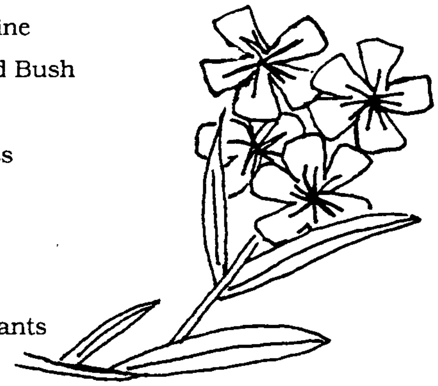


Crape Myrtle
Redwoods
Star Jasmine
Holly
Deodar Cedar



Plants that would probably do well with graywater irrigation are:

Oleander	Italian Stone Pine
Bougainvillea	Purple Hopseed Bush
Fan & Date Palms	Oaks
Rose	Arizona Cypress
Rosemary	Cottonwood
Agapanthus	Olive
Bermuda Grass	Ice Plant
Honeysuckle	many native plants
Australian Tea Tree	Juniper



Monitor and Maintain the System

If you have someone else install your graywater system, the installer will provide an operation and maintenance manual. That person will recommend such practices as checking the pump, filters, main lines, and other lines to keep your system in top condition.

It is important to check your system on a regular basis, every week or so, to see that graywater is not surfacing, that the plants and soils are healthy, and that the equipment is working properly.

The pump is an important part of the graywater system. Read the pump's instruction guide carefully. Adjust the pump's float switch to turn on as early as possible to avoid an overflowing tank. Be sure to connect the grounded, three-pronged cord supplied with the pump to an approved Ground Fault Intercept outlet. The pump runs off standard house current, so special wiring is not necessary.

A pump should not be run without a check-valve, which is installed between the pump and the first irrigation point. The check-valve allows water to pass in only one direction--toward the landscape, and not back into the tank. Without a check-valve, water draining back into the tank would activate the pump and the pump would run continuously.

The main concern people have with drip irrigation systems is the possible clogging of the emitters, preventing the flow of water to the plants. With properly selected and maintained filtration and occasional flushing of the subsurface drip irrigation system, most problems with emitter clogging can be avoided. If clogging does occur, simple chemical solutions can be used to clear the emitters.

The 3-way diverter valve (or washing machine "Y" valve) which was installed as part of the graywater system allows the graywater to be sent back to the sewer/septic line when rain has saturated the soil. Turning the graywater system off during the rainy season will help keep the soil healthy because the rain will leach away any soap buildup. The diverter valve is also employed to send water with caustic cleaners or strong bleaches to the sewer/ septic line.

APPENDIX J

Graywater Systems for Single-family Dwellings

J 1 Graywater Systems (General)

(a) The provisions of this Appendix shall apply to the construction, alteration and repair of graywater systems for subsurface landscape irrigation. Installations shall be allowed only in single-family dwellings. The system shall have no connection to any potable water system and shall not result in any surfacing of the graywater. Except as otherwise provided for in this Appendix, the provisions of the Uniform Plumbing Code (U.P.C.) shall be applicable to graywater installations.

(b) The type of system shall be determined on the basis of location, soil type and ground water level and shall be designed to accept all graywater connected to the system from the residential building. The system shall discharge into subsurface irrigation fields and may include surge tank(s) and appurtenances, as required by the Administrative Authority.

(c) No graywater system, or part thereof, shall be located on any lot other than the lot which is the site of the building or structure which discharges the graywater; nor shall any graywater system or part thereof be located at any point having less than the minimum distances indicated in Table J-1.

(d) No permit for any graywater system shall be issued until a plot plan with appropriate data satisfactory to the Administrative Authority has been submitted and approved. When there is insufficient lot area or inappropriate soil conditions for adequate absorption of the graywater, as determined by the Administrative Authority, no graywater system shall be permitted. The Administrative Authority is a city or county.

(e) No permit shall be issued for a graywater system which would adversely impact a geologically sensitive area, as determined by the Administrative Authority.

(f) Private sewage disposal systems existing or to be constructed on the premises shall comply with Appendix I of this Code or applicable local ordinance. When abandoning underground tanks, Section 1119 of the U.P.C. shall apply. Also, appropriate clearances from graywater systems shall be maintained as provided in Table J-1. The capacity of the private sewage disposal system, including required future areas, shall not be decreased by the existence or proposed installation of a graywater system servicing the premises.

(g) Installers of graywater systems shall provide an operation and maintenance manual. acceptable to the Administrative Authority. to the owner of each system. Graywater systems require regular or periodic maintenance.

(h) The Administrative Authority shall provide the applicant a copy of this Appendix.

J 2 Definitions

Graywater is untreated household waste water which has not come into contact with toilet waste. Graywater includes used water from bathtubs, showers, bathroom wash basins, and water from clothes washing machines and laundry tubs. It shall not include waste water from kitchen sinks, dishwashers or laundry water from soiled diapers.

Surfacing of graywater means the ponding, running off or other release of graywater from the land surface.

J 3 Permit

It shall be unlawful for any person to construct, install or alter, or cause to be constructed, installed or altered, any graywater system in a building or on a premises without first obtaining a permit to do such work from the Administrative Authority.

J 4 Drawings and Specifications

The Administrative Authority may require any or all of the following information to be included with or in the plot plan before a permit is issued for a graywater system:

(a) Plot plan drawn to scale completely dimensioned, showing lot lines and structures, direction and approximate slope of surface, location of all present or proposed retaining walls, drainage channels, water supply lines, wells, paved areas and structures on the plot, number of bedrooms and plumbing fixtures in each structure, location of private sewage disposal system and 100 percent expansion area or building sewer connecting to public sewer, and location of the proposed graywater system.

(b) Details of construction necessary to ensure compliance with the requirements of this Appendix together with a full description of the complete installation, including installation methods, construction and materials as required by the Administrative Authority.

(c) A log of soil formations and ground water level as determined by test holes dug in close proximity to any proposed irrigation area, together with a statement of water absorption characteristics of the soil at the proposed site as determined by approved percolation tests. In lieu of

percolation tests, the Administrative Authority may allow the use of Table J-2, an infiltration rate designated by the Administrative Authority, or an infiltration rate determined by a test approved by the Administrative Authority.

J 5 Inspection and Testing

(a) Inspection

(1) All applicable provisions of this Appendix and of Section 318 of the U.P.C. shall be complied with.

(2) System components shall be properly identified as to manufacturer.

(3) Surge tanks shall be installed on dry, level, well-compacted soil if in a drywell, or on a level, 3-inch concrete slab or equivalent, if above ground.

(4) Surge tanks shall be anchored against overturning.

(5) If the irrigation design is predicated on soil tests, the irrigation field shall be installed at the same location and depth as the tested area.

(6) Installation shall conform with the equipment and installation methods identified in the approved plans.

(7) Graywater stub-out plumbing may be allowed for future connection prior to the installation of irrigation lines and landscaping. Stub-out shall be permanently marked GRAYWATER STUB-OUT, DANGER—UNSAFE WATER.

(b) Testing

(1) Surge tanks shall be filled with water to the overflow line prior to and during inspection. All seams and joints shall be left exposed and the tank shall remain watertight.

(2) A flow test shall be performed through the system to the point of graywater irrigation. All lines and components shall be watertight.

J 6 Procedure for Estimating Graywater Discharge

The Administrative Authority may utilize the graywater discharge procedure listed below, water use records, or calculations of local daily per person interior water use:

(a) The number of occupants of each dwelling unit shall be calculated as follows:

First bedroom	2 occupants
Each additional bedroom	1 occupant

(b) The estimated graywater flows for each occupant shall be calculated as follows:

Showers, bathtubs and wash basins	25 GPD/occupant
Laundry	15 GPD/occupant

(c) The total number of occupants shall be multiplied by the applicable estimated graywater discharge as provided above and the type of fixtures connected to the graywater system.

J 7 Required Area of Subsurface Irrigation

Each irrigation zone shall have a minimum effective irrigation area for the type of soil and infiltration rate to distribute all graywater produced daily, pursuant to Section J-6, without surfacing. The required irrigation area shall be based on the estimated graywater discharge, pursuant to Section J-6 of this Appendix, size of surge tank, or a method determined by the Administrative Authority. Each proposed graywater system shall include at least two irrigation zones and each irrigation zone shall be in compliance with the provisions of this Section.

If the mini-leachfield irrigation system is used, the required square footage shall be determined from Table J-2, or equivalent, for the type of soil found in the excavation. The area of the irrigation field shall be equal to the aggregate length of the perforated pipe sections within the irrigation zone times the width of the proposed mini-leachfield trench.

No irrigation point shall be within 5 vertical feet of highest known seasonal groundwater nor where graywater may contaminate the ground water or ocean water. The applicant shall supply evidence of ground water depth to the satisfaction of the Administrative Authority.

J 8 Determination of Irrigation Capacity

(a) In order to determine the absorption quantities of questionable soils other than those listed in Table J-2, the proposed site may be subjected to percolation tests acceptable to the Administrative Authority or determined by the Administrative Authority.

(b) When a percolation test is required, no mini-leachfield system or subsurface drip irrigation system shall be permitted if the test shows the absorption capacity of the soil is less than 60 minutes/inch or more rapid than five minutes/inch, unless otherwise permitted by the Administrative Authority.

(c) The irrigation field size may be computed from Table J-2, or determined by the Administrative Authority or a designee of the Administrative Authority.

J 9 Surge Tank Construction (Figures 1, 2, 3 and 4)

(a) Plans for surge tanks shall be submitted to the Administrative Authority for approval. The plans shall show the data required by the Administrative Authority and may include dimensions, structural calculations, and bracing details.

(b) Surge tanks shall be constructed of solid, durable materials, not subject to excessive corrosion or decay, and shall be watertight.

(c) Surge tanks shall be vented as required by Chapter 5 of this Code and shall have a locking, gasketed access opening, or approved equivalent, to allow for inspection and cleaning.

(d) Surge tanks shall have the rated capacity permanently marked on the unit. In addition, GRAYWATER IRRIGATION SYSTEM. DANGER—UNSAFE WATER shall be permanently marked on the surge tank.

(e) Surge tanks installed above ground shall have a drain and overflow, separate from the line connecting the tank with the irrigation fields. The drain and overflow shall have a permanent connection to a sewer or to a septic tank, and shall be protected against sewer line backflow by a backwater valve. The overflow shall not be equipped with a shutoff valve.

(f) The overflow and drain pipes shall not be less in diameter than the inlet pipe. The vent size shall be based on the total graywater fixture units, as outlined in U.P.C. Table 4-3 or local equivalent. Unions or equally effective fittings shall be provided for all piping connected to the surge tank.

(g) Surge tanks shall be structurally designed to withstand anticipated loads. Surge tank covers shall be capable of supporting an earth load of not less than 300 pounds per square foot when the tank is designed for underground installation.

(h) Surge tanks may be installed below ground in a dry well on compacted soil, or buried if the tank design is approved by the Administrative Authority. The system shall be designed so that the tank overflow will gravity drain to a sanitary sewer line or septic tank. The tank must be protected against sewer line backflow by a backwater valve.

(i) Materials

(1) Surge tanks shall meet nationally recognized standards for nonpotable water and shall be approved by the Administrative Authority.

(2) Steel surge tanks shall be protected from corrosion, both externally and internally, by an approved coating or by other acceptable means.

J 10 Valves and Piping (Figures 1, 2, 3 and 4)

Graywater piping discharging into a surge tank or having a direct connection to a sanitary drain or sewer piping shall be downstream of an approved waterseal-type trap(s). If no such trap(s) exists, an approved vented running trap shall be installed upstream of the connection to protect the building from any possible waste or sewer gases. All graywater piping shall be marked or shall have a continuous tape marked with the words DANGER—UNSAFE WATER. All valves, including the three-way valve, shall be readily accessible and shall be approved by the Administrative Authority. A backwater valve, installed pursuant to this Code, shall be provided on all surge tank drain connections to the sanitary drain or sewer piping.

J 11 Irrigation Field Construction

The Administrative Authority may permit subsurface drip irrigation, mini-leachfield or other equivalent irrigation methods which discharge graywater in a manner which ensures that the graywater does not surface. Design standards for subsurface drip irrigation systems and mini-leachfield irrigation systems follow:

(a) Standards for a subsurface drip irrigation system are:

(1) Minimum 140 mesh (115 micron) 1-inch filter with a capacity of 25 gallons per minute, or equivalent, filtration shall be used. The filter backwash and flush discharge shall be caught, contained and disposed of to the sewer system, septic tank or, with approval of the Administrative Authority, a separate mini-leachfield sized to accept all the backwash and flush discharge water. Filter backwash water and flush water shall not be used for any purpose. Sanitary procedures shall be followed when handling filter backwash and flush discharge or graywater.

(2) Emitters shall have a minimum flow path of 1,200 microns and shall have a coefficient of manufacturing variation (Cv) of no more than 7 percent. Irrigation system design shall be such that emitter flow variation shall not exceed ± 10 percent. Emitters shall be recommended by the manufacturer for subsurface use and graywater use, and shall have demonstrated resistance to root intrusion. For emitter ratings, refer to Irrigation Equipment Performance Report, Drip Emitters and Micro-Sprinklers, Center for Irrigation Technolo-

gy, California State University, 5730 N. Chestnut Avenue, Fresno, California 93740-0018.

(3) Each irrigation zone shall be designed to include no less than the number of emitters specified in Table J-3, or through a procedure designated by the Administrative Authority. Minimum spacing between emitters is 14 inches in any direction.

(4) The system design shall provide user controls, such as valves, switches, timers and other controllers, as appropriate, to rotate the distribution of graywater between irrigation zones.

(5) All drip irrigation supply lines shall be PVC Class 200 pipe or better and Schedule 40 fittings. All joints shall be properly glued, inspected and pressure tested at 40 psi, and shown to be drip tight for five minutes, before burial. All supply lines will be buried at least 8 inches deep. Drip feeder lines can be poly or flexible PVC tubing and shall be covered to a minimum depth of 9 inches.

(6) Where pressure at the discharge side of the pump exceeds 20 psi, a pressure-reducing valve able to maintain downstream pressure no greater than 20 psi shall be installed downstream from the pump and before any emission device.

(7) Each irrigation zone shall include an automatic flush valve/vacuum breaker to prevent back siphonage of water and soil.

(b) Standards for the mini-leachfield system are (Figure 5):

(1) Perforated sections shall be a minimum 3-inch diameter and shall be constructed of perforated high-density polyethylene pipe, perforated ABS pipe, perforated PVC pipe, or other approved materials, provided that sufficient openings are available for distribution of the graywater into the trench area. Material, construction and perforation of the piping shall be in compliance with the appropriate absorption field drainage piping standards and shall be approved by the Administrative Authority.

(2) Clean stone, gravel or similar filter material acceptable to the Administrative Authority, and varying in size between $^3/_4$ inch to $2^1/_2$ inches shall be placed in the trench to the depth and grade required by this Section. Perforated sections shall be laid on the filter material in an approved manner. The perforated sections shall then be covered with filter material to the minimum depth required by this Section. The filter material shall then be covered with landscape filter fabric or similar porous material to prevent closure of voids with earth backfill. No earth backfill shall be placed over the filter material cover until after inspections and acceptance.

(3) Irrigation fields shall be constructed as follows:

	Minimum	Maximum
Number of drain lines per irrigation zone	1	—
Length of each perforated line	—	100 feet
Bottom width of trench	6 inches	18 inches
Total depth of trench	17 inches	18 inches
Spacing of lines, center to center	4 feet	—
Depth of earth cover of lines	9 inches	—
Depth of filter material cover of lines	2 inches	—
Depth of filter material beneath lines	3 inches	—
Grade of perforated lines	level	3 inches/100 feet

J 12 Special Provisions

(a) Other collection and distribution systems may be approved by the Administrative Authority as allowed by Section 201 of the U.P.C.

(b) Nothing contained in this Appendix shall be construed to prevent the Administrative Authority from requiring compliance with stricter requirements than those contained herein, where such stricter requirements are essential in maintaining safe and sanitary conditions or from prohibiting graywater systems.

J 13 Health and Safety

(a) Graywater may contain fecal matter as a result of bathing and/or washing of diapers and undergarments. Water containing fecal matter, if swallowed, can cause illness in a susceptible person.

(b) Graywater shall not include laundry water from soiled diapers.

(c) Graywater shall not be applied above the land surface or allowed to surface and shall not be discharged directly into or reach any storm sewer system or any water of the United States.

(d) Graywater shall be not be contacted by humans, except as required to maintain the graywater treatment and distribution system.

(e) Graywater shall not be used for vegetable gardens.

Table J-1 Location of Graywater System

Minimum Horizontal Distance From	Surge Tank (feet)	Irrigation Field (feet)
Buildings or structures[1]	5[2]	8[3]
Property line adjoining private property	5	5
Water supply wells[4]	50	100
Streams and lakes[4]	50	50
Seepage pits or cesspools	5	5
Disposal field and 100 percent expansion area	5	4[5]
Septic tank	0	5[6]
On-site domestic water service line	5	5[7]
Pressure public water main	10	10[8]
Water ditches	50	50

NOTES: When mini-leach fields are installed in sloping ground, the minimum horizontal distance between any part of the distribution system and ground surface shall be 15 feet.

[1]Including porches and steps, whether covered or uncovered, but does not include car-ports, covered walks, driveways and similar structures.

[2]The distance may be reduced to 0 feet for aboveground tanks if approved by the Administrative Authority.

[3]The distance may be reduced to 2 feet, with a water barrier, by the Administrative Authority, upon consideration of the soil expansion index.

[4]Where special hazards are involved, the distance may be increased by the Administrative Authority.

[5]Applies to the mini-leachfield type system only. Plus 2 feet for each additional foot of depth in excess of 1 foot below the bottom of the drain line.

[6]Applies to mini-leachfield-type system only.

[7]A 2-foot separation is required for subsurface drip systems.

[8]For parallel construction or for crossings, approval by the Administrative Authority shall be required.

Table J-2 Mini-Leachfield Design Criteria of Six Typical Soils

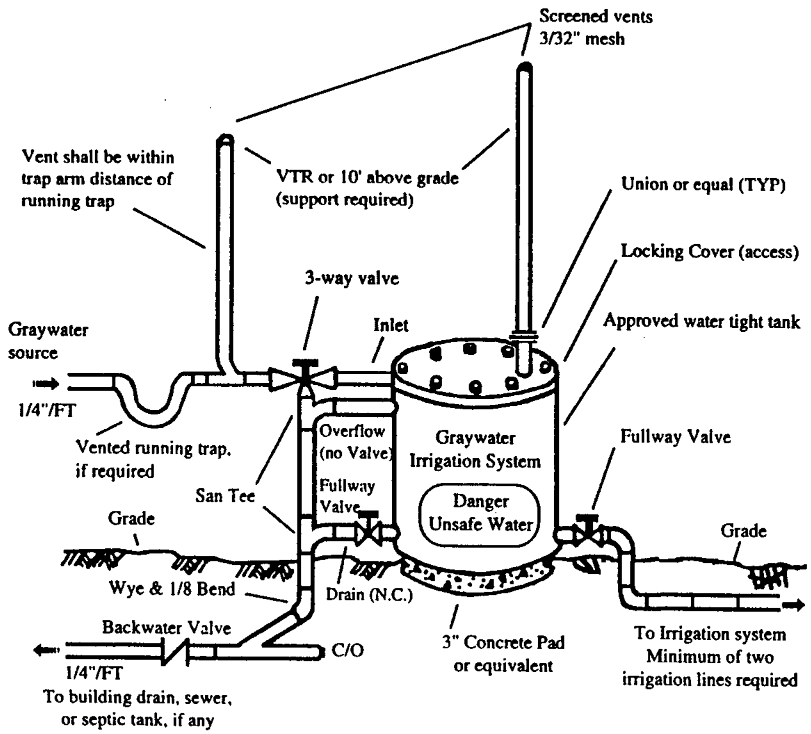
Type of Soil	Minimum sq. ft. of irrigation area per 100 gallons of estimated graywater discharge per day	Maximum absorption capacity, minutes per inch, of irrigation area for a 24-hour period
1. Coarse sand or gravel	20	5
2. Fine sand	25	12
3. Sandy loam	40	18
4. Sandy clay	60	24
5. Clay with considerable sand or gravel	90	48
6. Clay with small amount of sand or gravel	120	60

Table J-3 Subsurface Drip Design Criteria of Six Typical Soils

Type of Soil	Maximum emitter discharge (gal/day)	Minimum number of emitters per gpd of graywater production
1. Sand	1.8	0.6
2. Sandy loam	1.4	0.7
3. Loam	1.2	0.9
4. Clay loam	0.9	1.1
5. Silty clay	0.6	1.6
6. Clay	0.5	2.0

Use the daily graywater flow calculated in Section J-6 to determine the number of emitters per line.

GRAYWATER SYSTEMS FIGURE 1

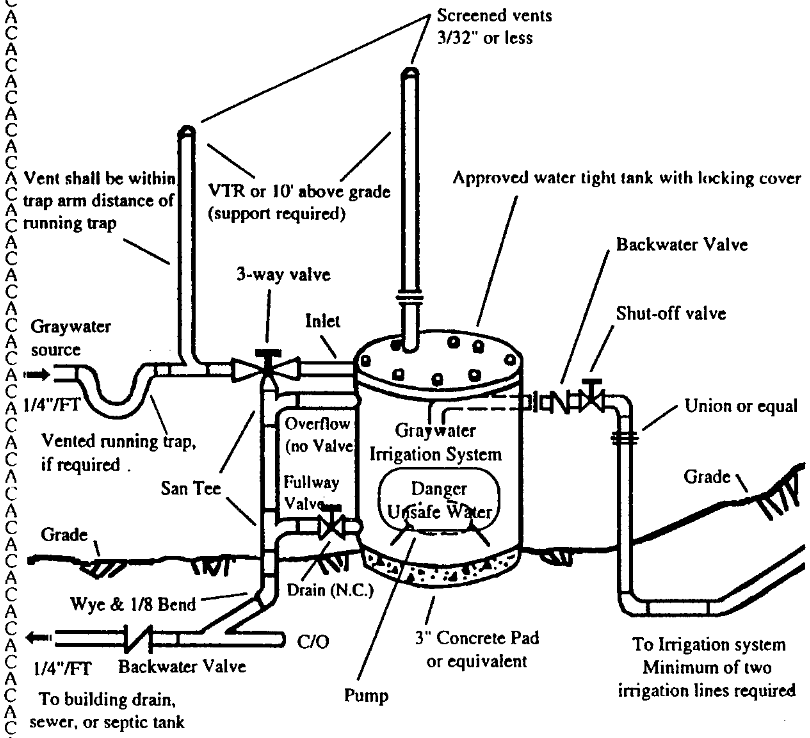


Abbreviations
C/O Cleanout
N.C. Normally Closed
VTR Vent Thru Roof

Figure 1—Graywater System Single Tank—Gravity (conceptual)

MAY 9, 1994

FIGURE 2 GRAYWATER SYSTEMS



Abbreviations
C/O Cleanout
N.C. Normally Closed
VTR Vent Thru Roof

Figure 2—Graywater System Single Tank—Pumped (conceptual)

MAY 9, 1994

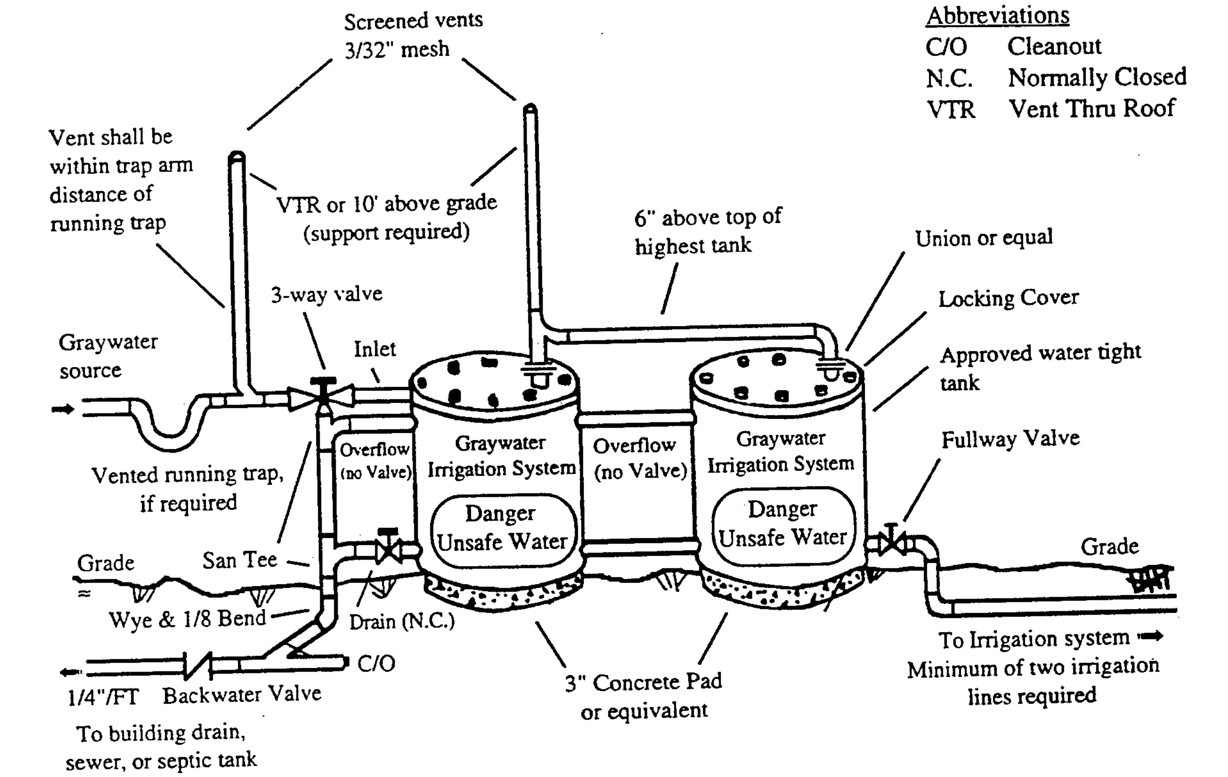


Figure 3—Graywater System Multiple Tank (conceptual)

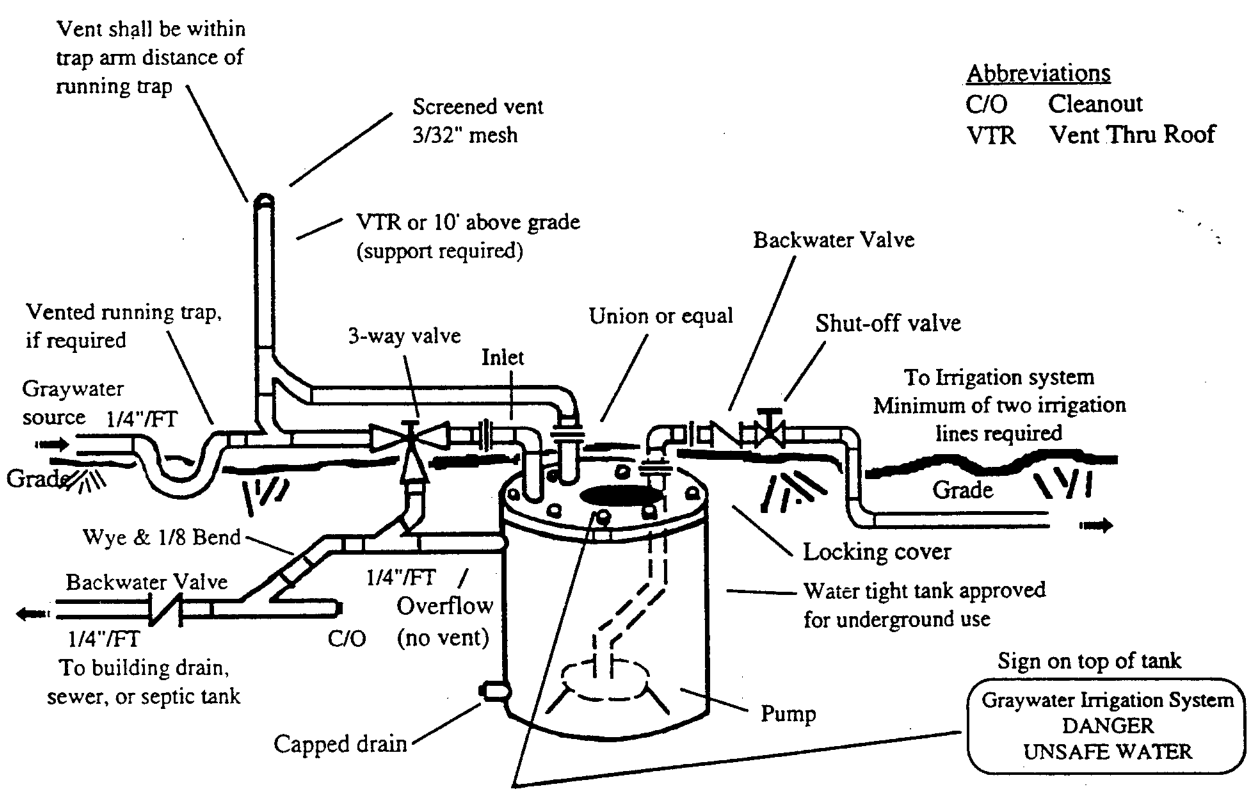


Figure 4—Graywater System Underground Tank (conceptual)

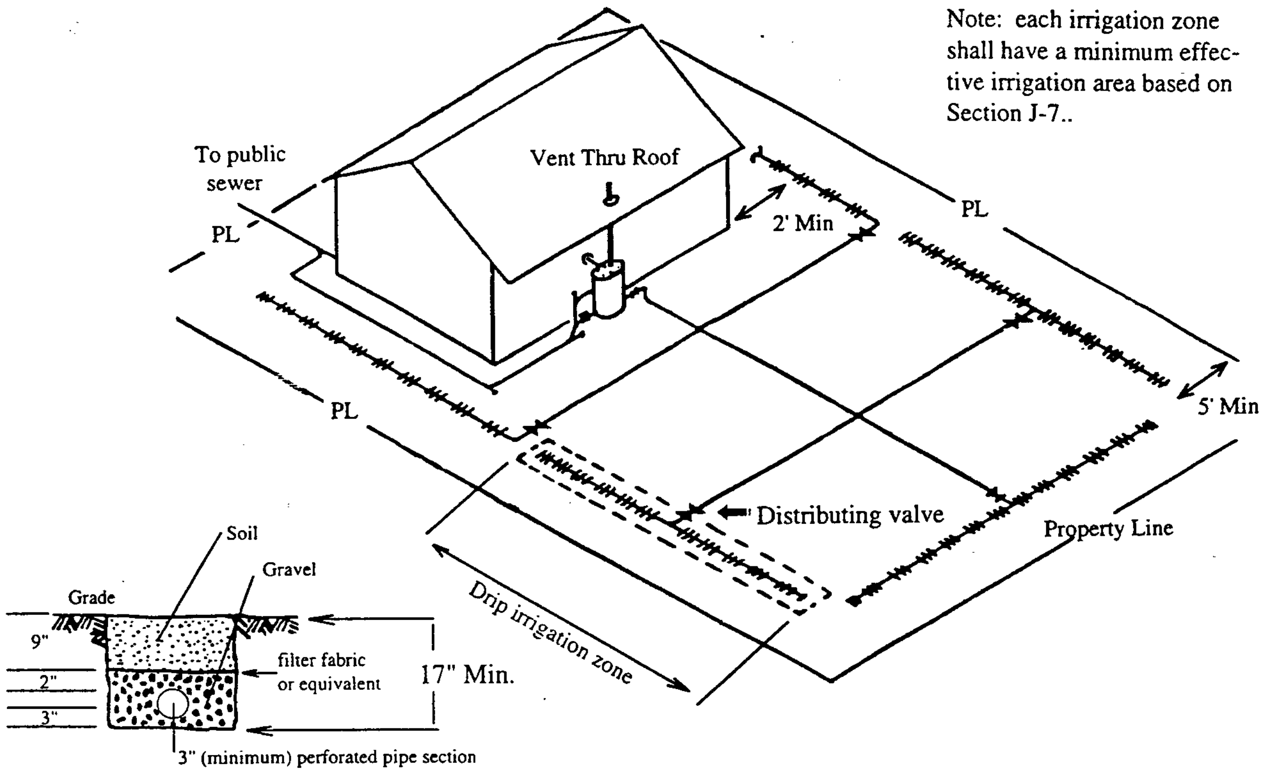


Figure 5—Graywater System Irrigation Layout (conceptual)

FIGURE 5

Graywater Measures Checklist

Description	Designer	Plan Checker	Inspector
Drawings and Specifications (J-4)			
(J-4, a) plot plan drawn to scale showing:			
lot lines and structure			
direction and approximate slope of surface			
location of retaining walls, drainage channels, water supply lines, wells			
location of paved areas and structures			
location of sewage disposal system and 100% expansion area			
location of graywater system (Table J-1 lists required distances)			
number of bedrooms and plumbing fixtures			
(J-4, b) details of contruction: installation, construction, and materials			
(J-4, c) log of soil formations, ground water level, water absorption of soil			
(J-7) no irrigation point within 5 ft. of highest known seasonal groundwater			
Estimating Graywater Discharge (J-6)			
bedroom #1 (2 occupants)			
additional bedrooms (1 occupant)			
showers, tubs, wash basins: 25 GPD/occupant			
laundry: 15 GPD/occupant			
Required Area (J-7)			
at least two irrigation zones			
each zone to distribute all graywater produced daily without surfacing			
meets Table J-2 design criteria of mini-leachfield OR			
meets Table J-2 design criteria for subsurface drip systems			
Surge Tanks (J-9)			
solid, durable material, watertight when filled, protected from corrosion			
(J-5, a) anchored on dry, level, compacted soil or 3 inch concrete slab			
meets standards for non-potable water			
vented with locking gasketed access opening			
capacity permanently marked on tank			
"GRAYWATER IRRIGATION SYSTEM, DANGER-UNSAFE WATER" permanently marked on tank			
drain and overflow permanently connected to sewer or septic tank			
Valves and Piping (J-10)			
piping downstream of waterseal type trap			
piping marked "DANGER-UNSAFE WATER"			
all valves readily accessible			
backwater valves on all surge tank drain connections to sanitary drain or sewer			
(J-5, a) stub-out plumbing permanently marked			

Graywater Measures Checklist

Description	Designer	Plan Checker	Inspector
Subsurface drip irrigation systems (J-11, a)			
minimu m 140 mesh (115 micron) one inch filter, with a 25 gpm capacity			
filter back-wash to the sewer system or septic tank			
emitter flow path of 1200 microns			
cv no more than 7%, flow variation no more than 10%			
emitters resistant to root intrusion (see CIT list)			
number of emitters determined from Table J-3, minimum spacing 14 inches			
supply lines of PVC class 200 pipe or better and schedule 40 fittings, when			
pressure tested at 40 psi, drip-tight for 5 minutes			
supply lines 8 inches deep, feeder lines (poly or flexible PVC) 9 inches deep			
downstream pressure does not exceed 20 psi (pounds per square inch)			
each irrigation zone has automatic flush valve/vacuum breaker			
Mini-leachfield systems (J-11, b)			
perforated lines minimum 3 inches diameter			
high density polyethylene pipe, perforated ABS pipe, or perforated PVC pipe			
maximum length of perofrated line- 100 feet			
maximum grade- 3 inches/100 feet			
minimum spacing- 4 feet			
earth cover of lines at least 9 inches			
clean stone or gravel filter material from 3/4 to 2 1/2 inch size in trench 3 inch			
deep beneath lines and 2 inches above			
filter fabric covers filter material			
Inspection (J-5, a)			
system components identified as to manufacturer			
irrigation field installed at same location as soil test, if required			
installation conforms with approved plans			
Testing (J-5, b)			
surge tank remains watertight as tank is filled with water			
flow test shows all lines and componints remain watertight			

What Can I Irrigate?

Greywater can be used to irrigate fruit trees, groundcovers and ornamental trees and shrubs. Salt-tolerant plants such as oleander, bermuda grass, date palms, and native desert plants are well-suited to irrigation with greywater. Avoid using greywater on plants that prefer acid conditions, such as:

Ash	Foxglove	Philodendron	Hydrangea	Camellia
Azalea	Gardenia	Primrose	Oxalis	Xylosma
Begonia	Hibiscus	Rhododendron	Violet	Fern
Dicentra	Impatiens			

Sandy soils are less vulnerable to damage than clay soils because they drain better. In very low rainfall areas, apply fresh water occasionally to leach out accumulated salts. Be aware that some harmful effects are not always visible immediately and may take one or two years to appear. In any case, you should always pay attention to the health of the plants being irrigated and discontinue using greywater if signs of stress are observed.

About The Study

All the detergents and related clothes-washing products were purchased in Tucson during May, 1992. The amounts used were based on the manufacturers' recommended levels for a cool- to warm-water wash in a top-loading machine. Distilled water was used as a source to minimize the effect of widely-varying salt and mineral levels in tap water. The list is presented in alphabetical order and is intended as a basis for comparison only. No endorsement of any product is intended.

This study was based in part on research conducted by the Pima County Extension Service, and was prepared by the Office of Arid Lands Studies, in cooperation with the Soil, Water and Plant Analysis Laboratory, University of Arizona, and sponsored by Tucson Water.

For more information...

on legal requirements to operate a greywater system,
contact Pima County Department of Environmental Quality at **740-3340**
or Arizona Dept. of Environmental Quality in Tucson at **628-6733**
or call **1-800-234-5677, ext. 4667.**

on greywater systems or water conservation, call Tucson Water at **791-4331.**

tucson water

City of Tucson TDD number (Telecommunication Device for the Deaf) **791-2639**

WCO/3-93

Printed on recycled paper

GREYWATER AND YOUR DETERGENT

This pamphlet is intended for those conservation-minded people who would like to use washing machine water (greywater) to irrigate their landscapes. **However, the use of greywater and operation of greywater systems are carefully regulated by the Pima County Department of Environmental Quality and the Arizona Department of Environmental Quality.** Contact the Pima County Department of Environmental Quality at **740-3340** for requirements and regulations regarding permits for the construction, operation, and maintenance of greywater systems and use of greywater.

If you plan to use washing machine water to irrigate, you should be aware of the elements present in this water which may affect your plants or soils. Detergents and other clothes-washing products use a variety of chemicals to aid in cleansing. Some of these ingredients can be harmful to your plants. Because labeling on detergent and other clothes-washing products is often incomplete, a study was conducted to evaluate some critical product characteristics which may adversely affect the landscape, including alkalinity, boron, conductivity, sodium, and phosphate.

Alkalinity

Alkalinity refers to the relative amounts of alkaline chemicals in a solution. Sodium, potassium, and calcium are alkaline chemicals; they often are combined with carbonates, sulfates, or chlorides. Plants do not tolerate high concentrations of alkali salts.

Boron

Boron is considered a plant micronutrient, required in only very, very small amounts. Most soils provide adequate amounts of this chemical. Concentrations only slightly higher than those considered beneficial can cause severe injury or death to plants.

Conductivity

Conductivity is a simple measure of the amount of dissolved chemicals in a solution. These chemicals can be beneficial or harmful. The higher the conductivity, the more dissolved salts and minerals are present. In general, the higher the concentration of dissolved salts and minerals in the water, the greater the potential for adverse affects on the environment and plant health.

Sodium

Sodium can act as a plant poison by reducing the plant's ability to take up water from the soil. Too much sodium can destroy the structure of clay soils, making them slick and greasy by removing air spaces and thus preventing good drainage. Once a clay soil is damaged by sodium, it can be very difficult to restore it to a viable condition.

Phosphate

Phosphate is a plant food and is added to soil as a fertilizer. Soils in the Tucson area are typically low in phosphate; thus, there may be some benefit to plants if phosphate is present in greywater. This should not be relied upon, however, since many forms of phosphate are not readily usable by plants and soils.

Is Biodegradable Better?

The word biodegradable means that a complex chemical is broken down into simpler components through biological action. Do not be confused by the word biodegradable, which often is used to imply environmentally safe. Harmful chemicals as well as beneficial ones may be biodegradable.

A Note About Chlorine

Although chlorine in bleach and detergents is generally expended in the washing process, some may be left in the greywater that reaches plants. Chlorine should not be used in the garden because it may substitute for similar nutrients, blocking normal metabolic processes. The addition of chlorine to water used for irrigation should be kept to a minimum. Choose your detergent and clothes-washing products keeping in mind that it is better for your plants and soils to have a low alkalinity, boron, conductivity, and sodium content in the water. Personal preference may affect your choice of products, since higher levels of these constituents may add to their cleansing ability.

Product Name	P or L	Conductivity	Alkalinity	Sodium	Boron	Phosphate
Ajax Ultra	P	1130	219	292	0.040	11.2
Alfa Kleen	L	25.6	16.8	3.71	<<	<<<
All	P	2030	659	492	0.10	NT
All Regular	L	116	29.8	39.3	<<	<<<
Amway	P	939	310	227	<<	4.00
Ariel Ultra	P	1020	247	280	0.030	10.8
Arm and Hammer	P	2450	1160	572	<<	<<<
Bold	L	46.7	68.6	9.74	<<	<<<
Bonnie Hubbard Ultra	P	1560	617	377	0.036	<<<
Calgon Water Softener	P	1290	345	359	<<	22.9
Cheer Free	L	307	80.3	94.7	<<	<<<
Cheer Ultr	P	710	149	171	0.076	<<<
Chlorox 2	P	2880	1430	672	11.2	<<<
Dash	P	1060	482	238	2.14	<<<
Dreft Ultra	P	737	328	189	9.75	<<<
Downy Fabric Softener	L	6.37	NT	<	<<	<<<
Ecovcover	L	132	63.7	24.3	<<	<<<
ERA Plus	L	102	15.3	26.3	<<	<<<
Fab Ultra	P	1140	199	443	<<	21.7
Fab 1-Shot	Pkt	501	09	109	<<	5.26
Fresh Start	P	510	106	132	0.026	8.28
Gain Ultra	P	792	300	180	0.058	<<<
Greenmark	P	1690	568	395	<<	1.67
Ivory Snow	P	258	219	70.8	<<	NT
Oasis	L	89.6	16.2	<	<<	<<<
Oxydol Ultra	P	1030	501	272	11.3	<<<
Par All Temperature	P	2350	431	529	0.049	2.67
Purex Ultra	P	1010	278	231	<<	<<<
Sears Plus	P	2500	1200	635	<<	<<<
Shaklee	L	19.0	12.1	6.48	<<	<<<
Shaklee Basic L	P	1030	285	230	<<	<<<
Snuggle Fabric Softener	L	2.60	NT	<	<<	<<<
Sun Ultra	P	1490	653	335	<<	1.58
Surf Ultra	P	989	302	249	<<	13.7
Tide with Bleach	L	329	58.3	95.0	2.30	<<<
Tide Regular	L	291	61.2	93.8	0.030	<<<
Tide Ultra	P	959	236	243	0.098	10.7
Valu Time	P	1650	460	371	0.034	1.79
White King	P	266	165	74.0	1.83	NT
White Magic Ultra	P	1140	194	273	0.035	18.5
Wisk Advanced Action	L	221	72.4	56.8	7.41	<<<
Wisk Power Scoop	P	1160	360	319	<<	9.77
Woolite	P	1040	22.3	239	0.17	<<<
Yes	L	42.5	10.3	6.40	<<	<<<
Tap Water	n/a	317	118	42.7	0.042	<<<
Distilled/Deionized Water	n/a	2.03	3.78	<	<<	<<<

Legend: P: Powder L: Liquid
<: Less than the sodium detection limit of 1.0 mg/l.
<<: Less than the boron detectionlimit of 0.025 mg/l.
<<<: Less than the phosphate detection limit of 1.2 mg/l.
NT: Testing of sample not possible.

Historical Evapotranspiration Values in Inches for July

North Central Coast	monthly	weekly
Novato	5.9	1.3
San Francisco	4.5	1.0
Concord	7.0	1.6
San Jose	6.5	1.5
Monterey	4.3	1.0
San Luis Obispo	4.6	1.0
South Coastal		
Santa Barbara	5.5	1.3
Ventura	5.5	1.3
Los Angeles	6.6	1.5
Laguna Beach	4.9	1.1
San Diego	4.6	1.0
Central Valley		
Auburn	8.3	1.9
Sacramento	8.4	1.9
Modesto/Stockton	8.1	1.8
Fresno	8.4	1.9
Baskersfield	8.5	1.9
Redding	8.5	1.9
South Inland		
San Fernando	7.3	1.7
Pasadena	7.1	1.6
Riverside	7.9	1.8
Ramona	7.3	1.7
San Bernardino	7.9	1.8
High Desert		
Palmdale	9.9	2.3
Lancaster	11.0	2.5
Victorville	11.2	2.5
Bishop	7.4	1.7
Independence	9.8	2.2
Low Desert		
Palm Springs	11.6	2.6
Coachella	12.3	2.8
Needles	12.8	2.9
El Centro	11.6	2.6

Appendix C: Elements of Water Conservation

FROM: UTILITY DEPARTMENT, TOWN OF HENRIETTA, NEW YORK

COMMON CAUSES FOR WATER LEAKAGE: THINGS TO CHECK

1. Check all faucets for leaks.
2. Check garden hose bibs to make sure they are shut off. It is best to shut them off inside the basement or house.
3. Check toilets for leakage by using water with dye tablets dissolved in it.
4. Check dishwashers and washing machines for water flow when turned OFF.
5. Check hot water heater for discharge from safety relief valve or from storage tank.
6. Check lawn sprinkler system for inadequate or malfunctioning shut off valves.
7. Check water softener systems for continuous backwash cycling.
8. Check ice makers in refrigerators for overflow.
9. Check humidification systems on furnaces for overflow.
10. Check hot water heating systems for any leaking conditions.
11. If water service piping is under basement or slab floors; check for continuously running sump pumps.

A SIMPLE TEST OF YOUR SYSTEM:

Some water meters have a sweep hand or a triangular dial that indicate low flows of water.

1. Read the water meter and do not use any water for 12 to 24 hours.
2. Re-read the meter.
3. If the meter has moved ahead, then there are probably leaks in your service.

THINGS TO THINK ABOUT:

Do you pre-wash dishes before using the dishwasher? This could be wasting water.

Do you use the lowest water level settings on your clothes washer when you wash small loads?

Do you water your lawn during the heat of the day?

Do you refill your pool regularly or use a solar cover to lessen water evaporation?

Do you leave the faucet running while you are brushing your teeth?

When you shower, do you leave the shower running until you are out of hot water?

FROM: Shapiro 1993

Interior strategies.

- Use a large bucket to collect shower and bath water for reuse in the garden. Use smaller ones for sinks.

- Turn the water off or reduce the flow while washing one's hair and body, brushing teeth or shaving.

- Flush less often.

Exterior Strategies

- Turn the hose off while soaping the car - a running hose can waste up to 10 gal/minute.

- Repair leaky sprinkler heads and pipes and make sure sprinklers deliver water to the lawn and not hard surfaces.

- Use a broom instead of a hose or air-blower to clean streets and driveways. A hose wastes hundreds of gal of water per use.

- Water the lawn before sunrise or after sunset. However, night watering can promote thatch and fungus. This can reduce evaporation by 60 percent. Also, the wind generally blows strongest during the day, deflecting water from the lawn and onto hard surfaces.

- Occasionally aerate (poke holes in) the lawn to improve air circulation and water penetration.

- People generally overwater their lawns. Lawns can be watered twice per week when given good soaks. Less frequent deep soaks are more efficient than frequent short waterings. There is a simple procedure to find out how long to water, depending on how much water is delivered during a specific time interval. Some areas provide residents ET (Evapotranspiration) information to help calculate watering times.

FROM Anderson-Rodriguez and Adams (1993)

Anderson-Rodriguez and Adams (1993) present information from Santa Barbara County and their water conservation experiences including droughts. 2.0 gpm showerheads were given to customers, education was a large program including literature, public service announcements in the media, videos, seminars, conservation hotline, water audits for customers, school education, and use of tagged plants. Reference irrigation data was supplied to farmers and managers of large landscape areas, primarily turf, audits were offered for large landscape sites. Water conserving features were established for all new developments including new construction, condominium conversion and remodels with fixtures and water efficient landscaping and irrigation and limits on turf amounts.

They also describe measures in a drought contingency plan.

Stage I is voluntary measures through public education.

Stage II and III required mandatory water use restrictions and hiring of enforcement officers. Stage III restrictions included:

1. The use of running water for cleaning hard surfaces is prohibited.

2. The waste of water is prohibited.

3. The operation of and introduction of water into ornamental fountains and bodies of water is prohibited, except when water is recirculated and there is a sign adjacent to the fountain, which states that the water in the fountain is being recirculated and that the City is in a drought condition.

4. Operators of hotels, motels, and other commercial establishments offering lodgings shall post in each room a Notice of Drought Condition as approved by the Director of Public Works.

5. All restaurants that provide table service shall post, in a conspicuous place, a Notice of Drought Condition as approved by the Director of Public Works and shall refrain from serving water except on specific request by a customer.

6. The use of potable water for cleaning, irrigation and construction purposes, including, but not limited to, dust control, settling of backfill, flushing of plumbing lines, and washing of equipment, buildings and vehicles, shall be prohibited in all cases where the Director of Public Works has determined that use of reclaimed wastewater is a feasible alternative.

7. The irrigation of trees and shrubs shall be allowed by a hand-held bucket, a drip irrigation system, or micro-spray system. The irrigation of turf is prohibited.

8. Use of potable water on golf course greens shall be allowed at all hours for the purposes of cooling greens, germinating seed, leaching minerals, or promoting growth of turf.

9. Washing of boats and vehicles is allowed only at a car wash that recycles water or use 10 gal or less of water per cycle or with a bucket and hose equipped with a automatic shut-off nozzle.

10. The introduction of water into swimming and wading pools and spas is prohibited unless the pool or spa is equipped with a pool cover, in which case the amount of water introduced in any 1 month shall be limited to 20 percent of the volume of the pool or spa.

11. Any use of water that causes runoff to occur beyond the immediate vicinity of use is prohibited.

Other measures used by customers to cut water use during the drought included taking short showers, leaving the toilet unflushed, and saving shower water in a bucket.

The town of Goleta has had a history of water conserving measures adding self-closing faucets to the features already mentioned.

Also mentioned was a speakers bureau, brochures/handouts and a demonstration garden featuring over 250 varieties of drought tolerant plants. The irrigation system uses surface and subsurface drip, mini-spray, and low-volume heads. Water efficient landscape promotion with awards

Appendix D: Federal, State, and Community Water Consumption Standards

The Energy Policy Act of 1992 set Federal water consumption standards for plumbing fixtures manufactured after 1 January 1994, but in addition, many states and communities have also adopted water consumption standards for buildings within their boundaries. These standards may be more stringent than Federal standards set by the Energy Policy Act. Seventeen states and numerous local communities had adopted water conservation legislation, and three other states had water conservation legislation pending before the Energy Policy Act of 1992 was even signed. Many of these states and communities began their water conservation practices in the 1980s, the earliest of which was Goleta, CA, in 1983. Facilities should conform to both Federal and local water conservation standards.

These states and communities established their water conservation legislation and incorporated water efficiency plumbing-fixture standards in their plumbing and building codes for many different reasons, including:

- to preserve and protect their water sources, both surface and groundwater
- to ensure water availability for all beneficial uses
- to reduce water and energy costs
- to regulate the plumbing and fixture trade
- to protect health and the environment.

Above all, these states and communities recognize the value of water as a precious resource. Table A-1 shows Federal, state, and community water conservation standards.

Jurisdiction	Effective Date	Toilets[a] (gpf)	Urinals (gpf)	Showerheads (gpm)	Lavatory Faucets (gpm)	Kitchen Faucets (gpm)
Federal (Energy Policy Act)	1/1/94	1.6	1.0	2.5 @ 80 psi	2.5 @ 80 psi	2.5 @ 80 psi
Arizona	1/1/93	1.6	1.0	2.5 @ 80 psi	2.0 @ 80 psi	2.5 @ 80 psi
California	1/1/92	1.6	1.0	2.5 @ 80 psi	2.2 @ 60 psi[c]	2.2 @ 60 psi[c]
California, Goleta	1983	1.6	1.0	2.0 @ 80 psi	2.0 @ 80 psi	2.0 @ 80 psi
Florida, Tampa	6/1/90	1.6	1.0	2.5 @ 80 psi	2.0 @ 80 psi	2.0 @ 80 psi
Georgia						
Residential	4/1/92			2.5 @ 60 psi[b]		
Commercial	7/1/92	1.6	1.0	2.5 @ 60 psi[b]	2.0	2.0 @ 80 psi
Maryland, Aberdeen	3/30/90	1.6	1.0	2.5 @ 80 psi	2.0 @ 80 psi	2.0 @ 80 psi
Maryland,						
Calvert County	6/3/86	1.5	1.0	2.5 @ 90 psi	@ 80 psi	2.0 @ 80 psi
New York	1/1/90	1.5	1.0	2.5 @ 80 psi	2.0	2.0 @ 80 psi
Rhode Island	9/1/90	1.5	1.0	2.5 @ 80 psi	2.0 @ 80 psi	2.0 @ 80 psi
Texas	1/1/92	1.5	1.0	2.5 @ 80 psi	2.2 @ 60 psi[c]	2.2 @ 60 psi[c]
District of Columbia	1/1/92	1.5	1.0	2.5 @ 80 psi	2.0 @ 80 psi	2.2 @ 60 psi[c]

gpf = gallons per flush
gpm = gallons per minute
psi = pounds per square inch

Sources: Adapted from information provided by the Portland, Oregon, Bureau of Water Works; Amy Vickers and Associates; the National Wildlife Foundation; and Wade Miller Associates, Inc.

[a]The maximum water use allowed for any gravity tank-type white, two-piece toilet which bears an adhesive upon installation consisting of the words "Commercial Use Only" manufactured after 1 January 1994, and before 1 January 1997, is 3.5 gpf. The maximum water use allowed for flushometer valve toilets, other than, manufactured after 1 January 1997, is 1.6 gpf.
[b]2.5 gpm is equivalent to 2.9 gpm at 80 psi when measured at a test pressure of 60 psi.
[c]2.2 gpm is equivalent to 2.5 gpm at 80 psi when measured at a test pressure of 60 psi.

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